US009455138B1

(12) **United States Patent**
Fukazawa et al.

(10) **Patent No.: US 9,455,138 B1**
(45) **Date of Patent: Sep. 27, 2016**

(54) **METHOD FOR FORMING DIELECTRIC FILM IN TRENCHES BY PEALD USING H-CONTAINING GAS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/937,053**

(22) Filed: **Nov. 10, 2015**

(51) **Int. Cl.**
H01L 21/311 (2006.01)
H01L 21/02 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 21/0228*** (2013.01); ***H01L 21/02123*** (2013.01); ***H01L 21/02208*** (2013.01)

(58) **Field of Classification Search**
CPC H01L 21/0228; H01L 21/02123; H01L 21/02208; H01L 21/0262; H01L 21/02642; H01L 21/02219; H01L 21/3141; C23C 16/277; C23C 16/45525
USPC 438/680, 700, 142, 474, 475, 513, 515, 438/743, 744, 769, 791; 257/E21.006, 257/E21.054, E21.17, E21.267, E21.278, 257/E21.293, E21.311, E21.319, E21.321, 257/E21.327
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

D56,051 S 8/1920 Cohn
2,161,626 A 6/1939 Loughner et al.
2,745,640 A 5/1956 Cushman
2,990,045 A 9/1959 Root
3,089,507 A 5/1963 Drake et al.
3,094,396 A 6/1963 Sylvester et al.
3,232,437 A 2/1966 Hultgren
3,833,492 A 9/1974 Bollyky
3,854,443 A 12/1974 Baerg
3,862,397 A 1/1975 Anderson et al.
3,887,790 A 6/1975 Ferguson
(Continued)

FOREIGN PATENT DOCUMENTS

CN 1563483 1/2005
CN 101330015 12/2008
(Continued)

OTHER PUBLICATIONS

USPTO; Office Action dated Aug. 27, 2010 in U.S. Appl. No. 12/118,596.
(Continued)

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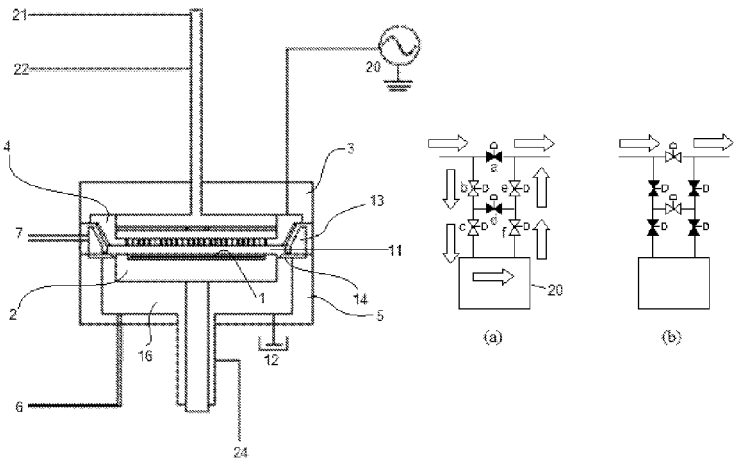
(57) **ABSTRACT**

A method for forming a dielectric film in a trench on a substrate by plasma-enhanced atomic layer deposition (PEALD) performs one or more process cycles, each process cycle including: (i) feeding a silicon-containing precursor in a pulse; (ii) supplying a hydrogen-containing reactant gas at a flow rate of more than about 30 sccm but less than about 800 sccm in the absence of nitrogen-containing gas; (iii) supplying a noble gas to the reaction space; and (iv) applying RF power in the presence of the reactant gas and the noble gas and in the absence of any precursor in the reaction space, to form a monolayer constituting a dielectric film on a substrate at a growth rate of less than one atomic layer thickness per cycle.

20 Claims, 2 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,054,071 A 10/1977 Patejak
4,058,430 A 11/1977 Suntola et al.
4,134,425 A 1/1979 Gussefeld et al.
4,145,699 A 3/1979 Hu et al.
4,176,630 A 12/1979 Elmer
4,181,330 A 1/1980 Kojima
4,194,536 A 3/1980 Stine et al.
4,322,592 A 3/1982 Martin
4,389,973 A 6/1983 Suntola et al.
4,393,013 A 7/1983 McMenamin
4,401,507 A 8/1983 Engle
4,414,492 A 11/1983 Hanlet
4,436,674 A 3/1984 McMenamin
4,479,831 A 10/1984 Sandow
4,499,354 A 2/1985 Hill et al.
4,512,113 A 4/1985 Budinger
4,570,328 A 2/1986 Price et al.
4,579,623 A 4/1986 Suzuki et al.
D288,556 S 3/1987 Wallgren
4,653,541 A 3/1987 Oehlschlaeger et al.
4,654,226 A 3/1987 Jackson et al.
4,681,134 A 7/1987 Paris
4,718,637 A 1/1988 Contin
4,722,298 A 2/1988 Rubin et al.
4,735,259 A 4/1988 Vincent
4,753,192 A 6/1988 Goldsmith et al.
4,756,794 A 7/1988 Yoder
4,780,169 A 10/1988 Stark et al.
4,789,294 A 12/1988 Sato et al.
4,821,674 A 4/1989 deBoer et al.
4,827,430 A 5/1989 Aid et al.
4,837,185 A 6/1989 Yau et al.
4,854,263 A 8/1989 Chang et al.
4,857,139 A 8/1989 Tashiro et al.
4,857,382 A 8/1989 Liu et al.
4,882,199 A 11/1989 Sadoway et al.
4,976,996 A 12/1990 Monkowski et al.
4,978,567 A 12/1990 Miller
4,984,904 A 1/1991 Nakano et al.
4,985,114 A 1/1991 Okudaira
4,986,215 A 1/1991 Yamada
4,987,856 A 1/1991 Hey
4,991,614 A 2/1991 Hammel
5,013,691 A 5/1991 Lory et al.
5,027,746 A 7/1991 Frijlink
5,028,366 A 7/1991 Harakal et al.
5,060,322 A 10/1991 Delepine
5,062,386 A 11/1991 Christensen
5,065,698 A 11/1991 Koike
5,074,017 A 12/1991 Toya et al.
5,098,638 A 3/1992 Sawada
5,104,514 A 4/1992 Quartarone
5,116,018 A 5/1992 Friemoth et al.
D327,534 S 6/1992 Manville
5,119,760 A 6/1992 McMillan et al.
5,167,716 A 12/1992 Boitnott et al.
5,178,682 A 1/1993 Tsukamoto et al.
5,183,511 A 2/1993 Yamazaki et al.
5,192,717 A 3/1993 Kawakami
5,194,401 A 3/1993 Adams et al.
5,199,603 A 4/1993 Prescott
5,221,556 A 6/1993 Hawkins et al.
5,242,539 A 9/1993 Kumihashi et al.
5,243,195 A 9/1993 Nishi
5,246,500 A 9/1993 Samata et al.
5,271,967 A 12/1993 Kramer et al.
5,288,684 A 2/1994 Yamazaki et al.
5,306,946 A 4/1994 Yamamoto
5,315,092 A 5/1994 Takahashi et al.
5,326,427 A 7/1994 Jerbic
5,336,327 A 8/1994 Lee
5,354,580 A 10/1994 Goela et al.
5,356,478 A 10/1994 Chen et al.
5,360,269 A 11/1994 Ogawa et al.
5,380,367 A 1/1995 Bertone
5,382,311 A 1/1995 Ishikawa et al.
5,404,082 A 4/1995 Hernandez et al.
5,413,813 A 5/1995 Cruse et al.
5,415,753 A 5/1995 Hurwitt et al.
5,421,893 A 6/1995 Perlov
5,422,139 A 6/1995 Fischer
5,430,011 A 7/1995 Tanaka et al.
5,494,494 A 2/1996 Mizuno et al.
5,496,408 A 3/1996 Motoda et al.
5,504,042 A 4/1996 Cho et al.
5,518,549 A 5/1996 Hellwig
5,527,417 A 6/1996 Iida et al.
5,531,835 A 7/1996 Fodor et al.
5,574,247 A 11/1996 Nishitani et al.
5,577,331 A 11/1996 Suzuki
5,589,002 A 12/1996 Su
5,589,110 A 12/1996 Motoda et al.
5,595,606 A 1/1997 Fujikawa et al.
5,601,641 A 2/1997 Stephens
5,604,410 A 2/1997 Vollkommer et al.
5,616,947 A 4/1997 Tamura
5,621,982 A 4/1997 Yamashita
5,632,919 A 5/1997 MacCracken et al.
D380,527 S 7/1997 Velez
5,679,215 A 10/1997 Barnes et al.
5,681,779 A 10/1997 Pasch et al.
5,683,517 A 11/1997 Shan
5,695,567 A 12/1997 Kordina
5,718,574 A 2/1998 Shimazu
5,724,748 A 3/1998 Brooks
5,728,223 A 3/1998 Murakami et al.
5,730,801 A 3/1998 Tepman et al.
5,732,744 A 3/1998 Barr et al.
5,736,314 A 4/1998 Hayes et al.
5,777,838 A 7/1998 Tamagawa et al.
5,781,693 A 7/1998 Balance et al.
5,796,074 A 8/1998 Edelstein et al.
5,801,104 A 9/1998 Schuegraf et al.
5,819,434 A 10/1998 Herchen et al.
5,827,757 A 10/1998 Robinson, Jr. et al.
5,836,483 A 11/1998 Disel
5,837,320 A 11/1998 Hampden-Smith et al.
5,852,879 A 12/1998 Schumaier
5,853,484 A 12/1998 Jeong
5,855,680 A 1/1999 Soininen et al.
5,855,681 A 1/1999 Maydan et al.
5,873,942 A 2/1999 Park
5,877,095 A 3/1999 Tamura et al.
D409,894 S 5/1999 McClurg
5,908,672 A 6/1999 Ryu
5,916,365 A 6/1999 Sherman
5,920,798 A 7/1999 Higuchi et al.
5,968,275 A 10/1999 Lee et al.
5,975,492 A 11/1999 Brenes
5,979,506 A 11/1999 Aarseth
5,997,588 A 12/1999 Goodwin
5,997,768 A 12/1999 Scully
D419,652 S 1/2000 Hall et al.
6,013,553 A 1/2000 Wallace
6,015,465 A 1/2000 Kholodenko et al.
6,017,779 A 1/2000 Miyasaka
6,024,799 A 2/2000 Chen
6,035,101 A 3/2000 Sajoto et al.
6,042,652 A 3/2000 Hyun
6,044,860 A 4/2000 Neu
6,050,506 A 4/2000 Guo et al.
6,060,691 A 5/2000 Minami et al.
6,074,443 A 6/2000 Venkatesh
6,083,321 A 7/2000 Lei et al.
6,086,677 A 7/2000 Umotoy et al.
6,099,302 A 8/2000 Hong et al.
6,122,036 A 9/2000 Yamasaki et al.
6,124,600 A 9/2000 Moroishi et al.
6,125,789 A 10/2000 Gupta et al.
6,129,044 A 10/2000 Zhao et al.
6,134,807 A 10/2000 Komino
6,137,240 A 10/2000 Bogdan et al.
6,140,252 A 10/2000 Cho et al.
6,148,761 A 11/2000 Majewski et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,160,244 A 12/2000 Ohashi
6,161,500 A 12/2000 Kopacz et al.
6,162,323 A 12/2000 Koshimizu et al.
6,180,979 B1 1/2001 Hofman et al.
6,187,691 B1 2/2001 Fukuda
6,190,634 B1 2/2001 Lieber et al.
6,194,037 B1 2/2001 Terasaki et al.
6,201,999 B1 3/2001 Jevtic
6,207,932 B1 3/2001 Yoo
6,212,789 B1 4/2001 Kato
6,218,288 B1 4/2001 Li et al.
6,250,250 B1 6/2001 Maishev et al.
6,271,148 B1 8/2001 Kao
6,274,878 B1 8/2001 Li et al.
6,281,098 B1 8/2001 Wang
6,287,965 B1 9/2001 Kang et al.
D449,873 S 10/2001 Bronson
6,296,909 B1 10/2001 Spitsberg
6,299,133 B2 10/2001 Waragai et al.
6,302,964 B1 10/2001 Umotoy et al.
6,303,523 B2 10/2001 Cheung
6,305,898 B1 10/2001 Yamagishi et al.
6,312,525 B1 11/2001 Bright et al.
6,315,512 B1 11/2001 Tabrizi et al.
D451,893 S 12/2001 Robson
D452,220 S 12/2001 Robson
6,325,858 B1 12/2001 Wengert
6,326,597 B1 12/2001 Lubomirsky et al.
6,329,297 B1 12/2001 Balish
6,342,427 B1 1/2002 Choi et al.
6,347,636 B1 2/2002 Xia
6,352,945 B1 3/2002 Matsuki
6,367,410 B1 4/2002 Leahey et al.
6,368,987 B1 4/2002 Kopacz et al.
6,370,796 B1 4/2002 Zucker
6,372,583 B1 4/2002 Tyagi
6,374,831 B1 4/2002 Chandran
6,375,312 B1 4/2002 Ikeda et al.
D457,609 S 5/2002 Piano
6,383,566 B1 5/2002 Zagdoun
6,383,955 B1 5/2002 Matsuki
6,387,207 B1 5/2002 Janakiraman
6,391,803 B1 5/2002 Kim et al.
6,398,184 B1 6/2002 Sowada et al.
6,410,459 B2 6/2002 Blalock et al.
6,413,321 B1 7/2002 Kim et al.
6,413,583 B1 7/2002 Moghadam et al.
6,420,279 B1 7/2002 Ono et al.
D461,233 S 8/2002 Whalen
D461,882 S 8/2002 Piano
6,435,798 B1 8/2002 Satoh
6,436,819 B1 8/2002 Zhang
6,437,444 B2 8/2002 Andideh
6,445,574 B1 9/2002 Saw et al.
6,446,573 B2 9/2002 Hirayama et al.
6,450,757 B1 9/2002 Saeki
6,454,860 B2 9/2002 Metzner et al.
6,455,445 B2 9/2002 Matsuki
6,461,435 B1 10/2002 Littau et al.
6,468,924 B2 10/2002 Lee
6,472,266 B1 10/2002 Yu et al.
6,475,276 B1 11/2002 Elers et al.
6,475,930 B1 11/2002 Junker et al.
6,478,872 B1 11/2002 Chae et al.
6,482,331 B2 11/2002 Lu et al.
6,482,663 B1 11/2002 Backland
6,483,989 B1 11/2002 Okada et al.
6,494,065 B2 12/2002 Babbitt
6,499,533 B2 12/2002 Yamada
6,503,562 B1 1/2003 Saito et al.
6,503,826 B1 1/2003 Oda
6,511,539 B1 1/2003 Raaijmakers
6,521,295 B1 2/2003 Remington
6,521,547 B1 2/2003 Chang et al.
6,528,430 B2 3/2003 Kwan
6,528,767 B2 3/2003 Bagley et al.
6,531,193 B2 3/2003 Fonash et al.
6,531,412 B2 3/2003 Conti et al.
6,534,395 B2 3/2003 Werkhoven et al.
6,558,755 B2 5/2003 Berry et al.
6,569,239 B2 5/2003 Arai et al.
6,573,030 B1 6/2003 Fairbairn et al.
6,576,062 B2 6/2003 Matsuse
6,576,064 B2 6/2003 Griffiths et al.
6,576,300 B1 6/2003 Berry et al.
6,579,833 B1 6/2003 McNallan et al.
6,583,048 B1 6/2003 Vincent et al.
6,590,251 B2 7/2003 Kang et al.
6,594,550 B1 7/2003 Okrah
6,598,559 B1 7/2003 Vellore et al.
6,627,503 B2 9/2003 Ma et al.
6,632,478 B2 10/2003 Gaillard et al.
6,633,364 B2 10/2003 Hayashi
6,635,117 B1 10/2003 Kinnard et al.
6,638,839 B2 10/2003 Deng et al.
6,645,304 B2 11/2003 Yamaguchi
6,648,974 B1 11/2003 Ogliari et al.
6,649,921 B1 11/2003 Cekic et al.
6,652,924 B2 11/2003 Sherman
6,673,196 B1 1/2004 Oyabu
6,682,973 B1 1/2004 Paton et al.
D486,891 S 2/2004 Cronce
6,688,784 B1 2/2004 Templeton
6,689,220 B1 2/2004 Nguyen
6,692,575 B1 2/2004 Omstead et al.
6,692,576 B2 2/2004 Halpin et al.
6,699,003 B2 3/2004 Saeki
6,709,989 B2 3/2004 Ramdani et al.
6,710,364 B2 3/2004 Guldi et al.
6,713,824 B1 3/2004 Mikata
6,716,571 B2 4/2004 Gabriel
6,723,642 B1 4/2004 Lim et al.
6,730,614 B1 5/2004 Lim et al.
6,734,090 B2 5/2004 Agarwala et al.
6,740,853 B1 5/2004 Johnson et al.
6,743,475 B2 6/2004 Skarp et al.
6,743,738 B2 6/2004 Todd et al.
6,753,507 B2 6/2004 Fure et al.
6,756,318 B2 6/2004 Nguyen et al.
6,759,098 B2 7/2004 Han
6,760,981 B2 7/2004 Leap
6,784,108 B1 8/2004 Donohoe et al.
D497,977 S 11/2004 Engelbrektsson
6,815,350 B2 11/2004 Kim et al.
6,820,570 B2 11/2004 Kilpela et al.
6,821,910 B2 11/2004 Adomaitis et al.
6,824,665 B2 11/2004 Shelnut et al.
6,825,134 B2 11/2004 Law et al.
6,846,515 B2 1/2005 Vrtis
6,847,014 B1 1/2005 Benjamin et al.
6,858,524 B2 2/2005 Haukka et al.
6,858,547 B2 2/2005 Metzner
6,863,019 B2 3/2005 Shamouilian
6,864,041 B2 3/2005 Brown
6,872,258 B2 3/2005 Park et al.
6,872,259 B2 3/2005 Strang
6,874,247 B1 4/2005 Hsu
6,874,480 B1 4/2005 Ismailov
6,875,677 B1 4/2005 Conley, Jr. et al.
6,876,017 B2 4/2005 Goodner
6,884,066 B2 4/2005 Nguyen et al.
6,884,319 B2 4/2005 Kim
6,889,864 B2 5/2005 Lindfors et al.
6,895,158 B2 5/2005 Aylward et al.
6,899,507 B2 5/2005 Yamagishi et al.
6,909,839 B2 6/2005 Wang et al.
6,911,092 B2 6/2005 Sneh
6,913,796 B2 7/2005 Albano et al.
6,930,059 B2 8/2005 Conley, Jr. et al.
6,935,269 B2 8/2005 Lee et al.
6,939,817 B2 9/2005 Sandhu et al.
6,951,587 B1 10/2005 Narushima
6,953,609 B2 10/2005 Carollo
6,955,836 B2 10/2005 Kumagai et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,972,478 B1 12/2005 Waite et al.
6,974,781 B2 12/2005 Timmermans et al.
6,976,822 B2 12/2005 Woodruff
6,984,595 B1 1/2006 Yamazaki
6,990,430 B2 1/2006 Hosek
7,021,881 B2 4/2006 Yamagishi
7,045,430 B2 5/2006 Ahn et al.
7,049,247 B2 5/2006 Gates et al.
7,053,009 B2 5/2006 Conley, Jr. et al.
7,055,875 B2 6/2006 Bonora
7,071,051 B1 7/2006 Jeon et al.
7,080,545 B2 * 7/2006 Dimeo, Jr. G01N 27/128 73/31.05
7,084,079 B2 8/2006 Conti et al.
7,088,003 B2 8/2006 Gates et al.
7,092,287 B2 8/2006 Beulens et al.
7,098,149 B2 8/2006 Lukas et al.
7,109,098 B1 9/2006 Ramaswamy et al.
7,115,838 B2 10/2006 Kurara et al.
7,122,085 B2 10/2006 Shero et al.
7,122,222 B2 10/2006 Xiao et al.
7,129,165 B2 10/2006 Basol et al.
7,132,360 B2 11/2006 Schaeffer et al.
7,135,421 B2 11/2006 Ahn et al.
7,143,897 B1 12/2006 Guzman et al.
7,147,766 B2 12/2006 Uzoh et al.
7,153,542 B2 12/2006 Nguyen et al.
7,163,721 B2 1/2007 Zhang et al.
7,163,900 B2 1/2007 Weber
7,172,497 B2 2/2007 Basol et al.
7,192,824 B2 3/2007 Ahn et al.
7,192,892 B2 3/2007 Ahn et al.
7,195,693 B2 3/2007 Cowans
7,201,943 B2 4/2007 Park et al.
7,204,887 B2 4/2007 Kawamura et al.
7,205,246 B2 4/2007 MacNeil et al.
7,205,247 B2 4/2007 Lee et al.
7,207,763 B2 4/2007 Lee
7,208,389 B1 4/2007 Tipton et al.
7,211,524 B2 5/2007 Ryu et al.
7,234,476 B2 6/2007 Arai
7,235,137 B2 6/2007 Kitayama et al.
7,235,482 B2 6/2007 Wu
7,235,501 B2 6/2007 Ahn et al.
7,238,596 B2 7/2007 Kouvetakis et al.
7,265,061 B1 9/2007 Cho et al.
D553,104 S 10/2007 Oohashi et al.
7,290,813 B2 11/2007 Bonora
7,294,582 B2 11/2007 Haverkort et al.
7,296,460 B2 * 11/2007 Dimeo, Jr. G01N 27/128 73/31.05
7,297,641 B2 11/2007 Todd et al.
7,298,009 B2 11/2007 Yan et al.
D557,226 S 12/2007 Uchino et al.
7,307,178 B2 12/2007 Kiyomori et al.
7,312,148 B2 12/2007 Ramaswamy et al.
7,312,162 B2 12/2007 Ramaswamy et al.
7,312,494 B2 12/2007 Ahn et al.
7,323,401 B2 1/2008 Ramaswamy et al.
7,326,657 B2 2/2008 Xia et al.
7,327,948 B1 2/2008 Shrinivasan
7,329,947 B2 2/2008 Adachi et al.
7,335,611 B2 2/2008 Ramaswamy et al.
7,354,847 B2 4/2008 Chan et al.
7,357,138 B2 4/2008 Ji et al.
7,381,644 B1 6/2008 Subramonium et al.
7,393,418 B2 7/2008 Yokogawa
7,393,736 B2 7/2008 Ahn et al.
7,393,765 B2 7/2008 Hanawa et al.
7,396,491 B2 7/2008 Marking et al.
7,399,388 B2 7/2008 Moghadam et al.
7,402,534 B2 7/2008 Mahajani
7,405,166 B2 7/2008 Liang et al.
7,405,454 B2 7/2008 Ahn et al.
D575,713 S 8/2008 Ratcliffe
7,411,352 B2 8/2008 Madocks
7,414,281 B1 8/2008 Fastow
7,416,989 B1 8/2008 Liu et al.
7,422,653 B2 9/2008 Blahnik et al.
7,422,775 B2 9/2008 Ramaswamy et al.
7,429,532 B2 9/2008 Ramaswamy et al.
7,431,966 B2 10/2008 Derderian et al.
7,437,060 B2 10/2008 Wang et al.
7,442,275 B2 10/2008 Cowans
7,475,588 B2 * 1/2009 Dimeo, Jr. G01N 27/128 73/31.05
7,476,291 B2 1/2009 Wang et al.
7,479,198 B2 1/2009 Guffrey
7,482,247 B1 * 1/2009 Papasouliotis C23C 16/045 438/437
D585,968 S 2/2009 Elkins et al.
7,489,389 B2 2/2009 Shibazaki et al.
7,494,882 B2 2/2009 Vitale
7,498,242 B2 3/2009 Kumar et al.
7,501,292 B2 3/2009 Matsushita et al.
7,503,980 B2 3/2009 Kida et al.
D590,933 S 4/2009 Vansell
7,514,375 B1 4/2009 Shanker et al.
D593,969 S 6/2009 Li
7,541,297 B2 6/2009 Mallick et al.
7,547,363 B2 6/2009 Tomiyasu et al.
7,550,396 B2 6/2009 Frohberg et al.
7,566,891 B2 7/2009 Rocha-Alvarez et al.
7,575,968 B2 8/2009 Sadaka et al.
7,579,785 B2 8/2009 Shinmen et al.
7,582,555 B1 9/2009 Lang
7,589,003 B2 9/2009 Kouvetakis et al.
7,589,029 B2 9/2009 Derderian et al.
D602,575 S 10/2009 Breda
7,598,513 B2 10/2009 Kouvetakis et al.
7,601,223 B2 10/2009 Lindfors et al.
7,601,225 B2 10/2009 Tuominen et al.
7,611,751 B2 11/2009 Elers
7,611,980 B2 11/2009 Wells et al.
7,618,226 B2 11/2009 Takizawa
D606,952 S 12/2009 Lee
7,629,277 B2 12/2009 Ghatnagar
7,632,549 B2 12/2009 Goundar
7,640,142 B2 12/2009 Tachikawa et al.
7,651,583 B2 1/2010 Kent et al.
7,651,961 B2 1/2010 Clark
D609,652 S 2/2010 Nagasaka
D609,655 S 2/2010 Sugimoto
7,678,197 B2 3/2010 Maki
7,678,715 B2 3/2010 Mungekar et al.
7,682,657 B2 3/2010 Sherman
D613,829 S 4/2010 Griffin et al.
D614,153 S 4/2010 Fondurulia et al.
D614,267 S 4/2010 Breda
D614,268 S 4/2010 Breda
D614,593 S 4/2010 Lee
7,690,881 B2 4/2010 Yamagishi
7,691,205 B2 4/2010 Ikedo
7,713,874 B2 5/2010 Milligan
7,720,560 B2 5/2010 Menser et al.
7,723,648 B2 5/2010 Tsukamoto et al.
7,727,864 B2 6/2010 Elers
7,732,343 B2 6/2010 Niroomand et al.
7,740,705 B2 6/2010 Li
7,745,346 B2 6/2010 Hausmann et al.
7,748,760 B2 7/2010 Kushida
7,754,621 B2 7/2010 Putjkonen
7,763,869 B2 7/2010 Matsushita et al.
7,767,262 B2 8/2010 Clark
7,771,796 B2 8/2010 Kohno et al.
7,780,440 B2 8/2010 Shibagaki et al.
7,789,965 B2 9/2010 Matsushita et al.
7,790,633 B1 9/2010 Tarafdar et al.
7,803,722 B2 9/2010 Liang
7,807,578 B2 10/2010 Bencher et al.
7,816,278 B2 10/2010 Reed et al.
7,824,492 B2 11/2010 Tois et al.
7,825,040 B1 11/2010 Fukazawa et al.
7,833,353 B2 11/2010 Furukawahara et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,838,084 B2 11/2010 Derderian et al.
7,842,518 B2 11/2010 Miyajima
7,842,622 B1 11/2010 Lee et al.
D629,874 S 12/2010 Hermans
7,851,019 B2 12/2010 Tuominen et al.
7,851,232 B2 12/2010 van Schravendijk et al.
7,865,070 B2 1/2011 Nakamura
7,884,918 B2 2/2011 Hattori
7,888,233 B1 2/2011 Gauri
D634,719 S 3/2011 Yasuda et al.
7,897,215 B1 3/2011 Fair et al.
7,902,582 B2 3/2011 Forbes et al.
7,910,288 B2 3/2011 Abatchev et al.
7,915,139 B1 3/2011 Lang
7,919,416 B2 4/2011 Lee et al.
7,925,378 B2 4/2011 Gilchrist et al.
7,935,940 B1 5/2011 Smargiassi
7,939,447 B2 5/2011 Bauer et al.
7,955,516 B2 6/2011 Chandrachood et al.
7,963,736 B2 6/2011 Takizawa et al.
7,972,980 B2 7/2011 Lee et al.
7,981,751 B2 7/2011 Zhu et al.
D643,055 S 8/2011 Takahashi
7,992,318 B2 8/2011 Kawaji
7,994,721 B2 8/2011 Espiau et al.
7,998,875 B2 8/2011 DeYoung
8,003,174 B2 8/2011 Fukazawa
8,004,198 B2 8/2011 Bakre et al.
8,020,315 B2 9/2011 Nishimura
8,030,129 B2 10/2011 Jeong
8,038,835 B2 10/2011 Hayashi et al.
8,041,197 B2 10/2011 Kasai et al.
8,041,450 B2 10/2011 Takizawa et al.
8,043,972 B1 10/2011 Liu et al.
8,055,378 B2 11/2011 Numakura
8,060,252 B2 11/2011 Gage et al.
8,071,451 B2 12/2011 Berry
8,071,452 B2 12/2011 Raisanen
8,072,578 B2 12/2011 Yasuda et al.
8,076,230 B2 12/2011 Wei
8,076,237 B2 12/2011 Uzoh
8,082,946 B2 12/2011 Laverdiere et al.
D652,896 S 1/2012 Grether
8,092,604 B2 1/2012 Tomiyasu et al.
D653,734 S 2/2012 Sisk
D654,884 S 2/2012 Honma
D655,055 S 2/2012 Toll
8,119,466 B2 2/2012 Avouris
8,137,462 B2 3/2012 Fondurulia et al.
8,137,465 B1 3/2012 Shrinivasan et al.
8,138,676 B2 3/2012 Mills
8,142,862 B2 3/2012 Lee et al.
8,143,174 B2 3/2012 Xia et al.
8,147,242 B2 4/2012 Shibagaki et al.
8,173,554 B2 5/2012 Lee et al.
8,187,951 B1 5/2012 Wang
8,192,901 B2 6/2012 Kageyama
8,196,234 B2 6/2012 Glunk
8,197,915 B2 6/2012 Oka et al.
8,216,380 B2 7/2012 White et al.
8,231,799 B2 7/2012 Bera et al.
D665,055 S 8/2012 Yanagisawa et al.
8,241,991 B2 8/2012 Hsieh et al.
8,242,031 B2 8/2012 Mallick et al.
8,252,114 B2 8/2012 Vukovic
8,252,659 B2 8/2012 Huyghebaert et al.
8,252,691 B2 8/2012 Beynet et al.
8,272,516 B2 9/2012 Salvador
8,278,176 B2 10/2012 Bauer et al.
8,282,769 B2 10/2012 Iizuka
8,287,648 B2 10/2012 Reed et al.
8,293,016 B2 10/2012 Bahng et al.
8,298,951 B1 10/2012 Nakano
8,307,472 B1 11/2012 Saxon et al.
8,309,173 B2 11/2012 Tuominen et al.
8,323,413 B2 12/2012 Son
8,329,599 B2 12/2012 Fukazawa et al.
8,334,219 B2 12/2012 Lee et al.
D676,943 S 2/2013 Kluss
8,367,528 B2 2/2013 Bauer et al.
8,372,204 B2 2/2013 Nakamura
8,393,091 B2 3/2013 Kawamoto
8,394,466 B2 3/2013 Hong et al.
8,415,259 B2 4/2013 Lee et al.
8,440,259 B2 5/2013 Chiang et al.
8,444,120 B2 5/2013 Gregg et al.
8,445,075 B2 5/2013 Xu et al.
8,465,811 B2 6/2013 Ueda
8,466,411 B2 6/2013 Arai
8,470,187 B2 6/2013 Ha
8,484,846 B2 7/2013 Dhindsa
8,492,170 B2 7/2013 Xie et al.
8,496,756 B2 7/2013 Cruse et al.
8,506,713 B2 8/2013 Takagi
8,535,767 B1 9/2013 Kimura
D691,974 S 10/2013 Osada et al.
8,551,892 B2 10/2013 Nakano
8,563,443 B2 10/2013 Fukazawa
8,569,184 B2 10/2013 Oka
8,591,659 B1 11/2013 Fang et al.
8,592,005 B2 11/2013 Ueda
8,608,885 B2 12/2013 Goto et al.
8,617,411 B2 12/2013 Singh
8,633,115 B2 1/2014 Chang et al.
8,647,722 B2 2/2014 Kobayashi et al.
8,664,627 B1 3/2014 Ishikawa et al.
8,667,654 B2 3/2014 Gros-Jean
8,668,957 B2 3/2014 Dussarrat et al.
8,669,185 B2 3/2014 Onizawa
8,683,943 B2 4/2014 Onodera et al.
8,711,338 B2 4/2014 Liu et al.
D705,745 S 5/2014 Kurs et al.
8,720,965 B2 5/2014 Hino et al.
8,722,546 B2 5/2014 Fukazawa et al.
8,726,837 B2 5/2014 Patalay et al.
8,728,832 B2 5/2014 Raisanen et al.
8,742,668 B2 6/2014 Nakano et al.
8,764,085 B2 7/2014 Urabe
8,784,950 B2 7/2014 Fukazawa et al.
8,784,951 B2 7/2014 Fukazawa et al.
8,785,215 B2 7/2014 Kobayashi et al.
8,790,743 B1 7/2014 Omori et al.
8,802,201 B2 8/2014 Raisanen et al.
8,820,809 B2 9/2014 Ando et al.
8,821,640 B2 9/2014 Cleary et al.
8,841,182 B1 9/2014 Chen et al.
8,845,806 B2 9/2014 Aida et al.
D715,410 S 10/2014 Lohmann
8,864,202 B1 10/2014 Schrameyer
D716,742 S 11/2014 Jang et al.
8,877,655 B2 11/2014 Shero et al.
8,883,270 B2 11/2014 Shero et al.
8,901,016 B2 12/2014 Ha et al.
8,911,826 B2 12/2014 Adachi et al.
8,912,101 B2 12/2014 Tsuji et al.
D720,838 S 1/2015 Yamagishi et al.
8,933,375 B2 1/2015 Dunn et al.
8,940,646 B1 1/2015 Chandrasekharan
D723,153 S 2/2015 Borkholder
8,946,830 B2 2/2015 Jung et al.
8,956,983 B2 2/2015 Swaminathan
D724,553 S 3/2015 Choi
D724,701 S 3/2015 Yamagishi et al.
D725,168 S 3/2015 Yamagishi
8,967,608 B2 3/2015 Mitsumori et al.
8,986,456 B2 3/2015 Fondurulia et al.
8,991,887 B2 3/2015 Shin et al.
8,993,054 B2 3/2015 Jung et al.
D726,365 S 4/2015 Weigensberg
D726,884 S 4/2015 Yamagishi et al.
9,005,539 B2 4/2015 Halpin et al.
9,017,481 B1 4/2015 Pettinger et al.
9,018,093 B2 4/2015 Tsuji et al.
9,018,111 B2 4/2015 Milligan et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,021,985 B2 5/2015 Alokozai et al.
9,023,737 B2 5/2015 Beynet et al.
9,029,253 B2 5/2015 Milligan et al.
9,029,272 B1 5/2015 Nakano
D732,145 S 6/2015 Yamagishi
D732,644 S 6/2015 Yamagishi et al.
D733,261 S 6/2015 Yamagishi et al.
D733,843 S 7/2015 Yamagishi et al.
D734,377 S 7/2015 Hirakida
D735,836 S 8/2015 Yamagishi
9,096,931 B2 8/2015 Yednak et al.
9,117,657 B2 8/2015 Nakano et al.
9,117,866 B2 8/2015 Marquardt et al.
D739,222 S 9/2015 Chadbourne
9,123,510 B2 9/2015 Nakano et al.
9,129,897 B2 * 9/2015 Pore H01L 21/28518
9,136,108 B2 9/2015 Matsushita et al.
9,142,393 B2 9/2015 Okabe et al.
9,169,975 B2 10/2015 Sarin et al.
9,171,714 B2 10/2015 Mori
9,171,716 B2 10/2015 Fukuda
D743,513 S 11/2015 Yamagishi
9,177,784 B2 11/2015 Raisanen et al.
9,190,263 B2 11/2015 Ishikawa et al.
9,196,483 B1 11/2015 Lee et al.
9,202,727 B2 12/2015 Dunn et al.
9,228,259 B2 1/2016 Haukka et al.
9,240,412 B2 1/2016 Xie et al.
2001/0017103 A1 8/2001 Takeshita et al.
2001/0018267 A1 8/2001 Shinriki et al.
2001/0019777 A1 9/2001 Tanaka et al.
2001/0019900 A1 9/2001 Hasegawa
2001/0028924 A1 10/2001 Sherman
2001/0046765 A1 11/2001 Cappellani et al.
2001/0049202 A1 12/2001 Maeda et al.
2002/0001974 A1 1/2002 Chan
2002/0011210 A1 1/2002 Satoh et al.
2002/0014204 A1 2/2002 Pyo
2002/0064592 A1 5/2002 Datta et al.
2002/0076507 A1 6/2002 Chiang et al.
2002/0079714 A1 6/2002 Soucy et al.
2002/0088542 A1 7/2002 Nishikawa et al.
2002/0098627 A1 7/2002 Pomarede et al.
2002/0108670 A1 8/2002 Baker et al.
2002/0110991 A1 8/2002 Li
2002/0114886 A1 8/2002 Chou et al.
2002/0115252 A1 8/2002 Haukka et al.
2002/0172768 A1 11/2002 Endo et al.
2002/0187650 A1 12/2002 Blalock et al.
2002/0197849 A1 12/2002 Mandal
2003/0003635 A1 1/2003 Paranjpe et al.
2003/0010452 A1 1/2003 Park et al.
2003/0012632 A1 1/2003 Saeki
2003/0019428 A1 1/2003 Ku et al.
2003/0019580 A1 1/2003 Strang
2003/0025146 A1 2/2003 Narwankar et al.
2003/0040158 A1 2/2003 Saitoh
2003/0042419 A1 3/2003 Katsumata et al.
2003/0049375 A1 3/2003 Nguyen et al.
2003/0054670 A1 3/2003 Wang et al.
2003/0059535 A1 3/2003 Luo et al.
2003/0059980 A1 3/2003 Chen et al.
2003/0066826 A1 4/2003 Lee et al.
2003/0075925 A1 4/2003 Lindfors et al.
2003/0082307 A1 5/2003 Chung et al.
2003/0091938 A1 5/2003 Fairbairn et al.
2003/0094133 A1 5/2003 Yoshidome et al.
2003/0111963 A1 6/2003 Tolmachev et al.
2003/0134038 A1 7/2003 Paranjpe
2003/0141820 A1 7/2003 White et al.
2003/0157436 A1 8/2003 Manger et al.
2003/0168001 A1 9/2003 Sneh
2003/0170583 A1 9/2003 Nakashima
2003/0180458 A1 9/2003 Sneh
2003/0183156 A1 10/2003 Dando
2003/0192875 A1 10/2003 Bieker et al.
2003/0198587 A1 10/2003 Kaloyeros
2003/0209323 A1 11/2003 Yokogaki
2003/0228772 A1 12/2003 Cowans
2003/0232138 A1 12/2003 Tuominen et al.
2004/0009679 A1 1/2004 Yeo et al.
2004/0013577 A1 1/2004 Ganguli et al.
2004/0013818 A1 1/2004 Moon et al.
2004/0016637 A1 1/2004 Yang et al.
2004/0018307 A1 1/2004 Park et al.
2004/0018750 A1 1/2004 Sophie et al.
2004/0023516 A1 2/2004 Londergan et al.
2004/0029052 A1 2/2004 Park et al.
2004/0036129 A1 2/2004 Forbes et al.
2004/0063289 A1 4/2004 Ohta
2004/0071897 A1 4/2004 Verplancken et al.
2004/0077182 A1 4/2004 Lim et al.
2004/0079960 A1 4/2004 Shakuda
2004/0080697 A1 4/2004 Song
2004/0082171 A1 4/2004 Shin et al.
2004/0101622 A1 5/2004 Park et al.
2004/0103914 A1 6/2004 Cheng et al.
2004/0106249 A1 6/2004 Huotari
2004/0124549 A1 7/2004 Curran
2004/0134429 A1 7/2004 Yamanaka
2004/0144980 A1 7/2004 Ahn et al.
2004/0146644 A1 7/2004 Xia et al.
2004/0168627 A1 9/2004 Conley et al.
2004/0169032 A1 9/2004 Murayama et al.
2004/0198069 A1 10/2004 Metzner et al.
2004/0200499 A1 10/2004 Harvey et al.
2004/0209477 A1 10/2004 Buxbaum et al.
2004/0212947 A1 10/2004 Nguyen
2004/0214445 A1 10/2004 Shimizu et al.
2004/0219793 A1 11/2004 Hishiya et al.
2004/0221807 A1 11/2004 Verghese et al.
2004/0247779 A1 12/2004 Selvamanickam et al.
2004/0261712 A1 12/2004 Hayashi et al.
2004/0266011 A1 12/2004 Lee et al.
2005/0003662 A1 1/2005 Jursich et al.
2005/0008799 A1 1/2005 Tomiyasu et al.
2005/0019026 A1 1/2005 Wang et al.
2005/0020071 A1 1/2005 Sonobe et al.
2005/0023624 A1 2/2005 Ahn et al.
2005/0034674 A1 2/2005 Ono
2005/0037154 A1 2/2005 Koh et al.
2005/0051093 A1 3/2005 Makino et al.
2005/0054228 A1 3/2005 March
2005/0059262 A1 3/2005 Yin et al.
2005/0064207 A1 3/2005 Senzaki et al.
2005/0064719 A1 3/2005 Liu
2005/0066893 A1 3/2005 Soininen
2005/0069651 A1 3/2005 Miyoshi
2005/0070123 A1 3/2005 Hirano
2005/0070729 A1 3/2005 Kiyomori et al.
2005/0072357 A1 4/2005 Shero et al.
2005/0074983 A1 4/2005 Shinriki et al.
2005/0092249 A1 5/2005 Kilpela et al.
2005/0095770 A1 5/2005 Kumagai et al.
2005/0100669 A1 5/2005 Kools et al.
2005/0101154 A1 5/2005 Huang
2005/0106893 A1 5/2005 Wilk
2005/0110069 A1 5/2005 Kil et al.
2005/0120962 A1 6/2005 Ushioda et al.
2005/0123690 A1 6/2005 Derderian et al.
2005/0133161 A1 6/2005 Carpenter et al.
2005/0142361 A1 6/2005 Nakanishi
2005/0145338 A1 7/2005 Park et al.
2005/0153571 A1 7/2005 Senzaki
2005/0173003 A1 8/2005 Laverdiere et al.
2005/0181535 A1 8/2005 Yun et al.
2005/0187647 A1 8/2005 Wang et al.
2005/0191828 A1 9/2005 Al-Bayati et al.
2005/0199013 A1 9/2005 Vandroux et al.
2005/0208718 A1 9/2005 Lim et al.
2005/0212119 A1 9/2005 Shero
2005/0214457 A1 9/2005 Schmitt et al.
2005/0214458 A1 9/2005 Meiere
2005/0218462 A1 10/2005 Ahn et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0221618 A1 10/2005 AmRhein et al.
2005/0223994 A1 10/2005 Blomiley et al.
2005/0227502 A1 10/2005 Schmitt et al.
2005/0229848 A1 10/2005 Shinriki
2005/0229972 A1 10/2005 Hoshi et al.
2005/0241176 A1 11/2005 Shero et al.
2005/0241763 A1 11/2005 Huang et al.
2005/0255257 A1 11/2005 Choi et al.
2005/0258280 A1 11/2005 Goto et al.
2005/0260347 A1 11/2005 Narwankar et al.
2005/0260850 A1 11/2005 Loke
2005/0263075 A1 12/2005 Wang et al.
2005/0263932 A1 12/2005 Heugel
2005/0271813 A1 12/2005 Kher et al.
2005/0274323 A1 12/2005 Seidel et al.
2005/0282101 A1 12/2005 Adachi
2005/0287725 A1 12/2005 Kitagawa
2005/0287771 A1 12/2005 Seamons et al.
2006/0013946 A1 1/2006 Park et al.
2006/0014384 A1 1/2006 Lee et al.
2006/0014397 A1 1/2006 Seamons et al.
2006/0016783 A1 1/2006 Wu et al.
2006/0019033 A1 1/2006 Muthukrishnan et al.
2006/0019502 A1 1/2006 Park et al.
2006/0021703 A1 2/2006 Umotoy et al.
2006/0024439 A2 2/2006 Tuominen et al.
2006/0046518 A1 3/2006 Hill et al.
2006/0051520 A1 3/2006 Behle et al.
2006/0051925 A1 3/2006 Ahn et al.
2006/0060930 A1 3/2006 Metz et al.
2006/0062910 A1 3/2006 Meiere
2006/0063346 A1 3/2006 Lee et al.
2006/0068121 A1 3/2006 Lee et al.
2006/0068125 A1 3/2006 Radhakrishnan
2006/0105566 A1 5/2006 Waldfried et al.
2006/0110934 A1 5/2006 Fukuchi
2006/0113675 A1 6/2006 Chang et al.
2006/0113806 A1 6/2006 Tsuji et al.
2006/0128168 A1 6/2006 Ahn et al.
2006/0130767 A1 6/2006 Herchen
2006/0137609 A1 6/2006 Puchacz et al.
2006/0147626 A1 7/2006 Blomberg
2006/0148180 A1 7/2006 Ahn et al.
2006/0163612 A1 7/2006 Kouvetakis et al.
2006/0172531 A1 8/2006 Lin et al.
2006/0191555 A1 8/2006 Yoshida et al.
2006/0193979 A1 8/2006 Meiere et al.
2006/0199357 A1 9/2006 Wan et al.
2006/0205223 A1 9/2006 Smayling
2006/0208215 A1 9/2006 Metzner et al.
2006/0213439 A1 9/2006 Ishizaka
2006/0223301 A1 10/2006 Vanhaelemeersch et al.
2006/0226117 A1 10/2006 Bertram et al.
2006/0228888 A1 10/2006 Lee et al.
2006/0236934 A1 10/2006 Choi et al.
2006/0240574 A1 10/2006 Yoshie
2006/0240662 A1 10/2006 Conley et al.
2006/0251827 A1 11/2006 Nowak
2006/0257563 A1 11/2006 Doh et al.
2006/0257584 A1 11/2006 Derderian et al.
2006/0258078 A1 11/2006 Lee et al.
2006/0258173 A1 11/2006 Xiao et al.
2006/0260545 A1 11/2006 Ramaswamy et al.
2006/0264060 A1 11/2006 Ramaswamy et al.
2006/0264066 A1 11/2006 Bartholomew
2006/0266289 A1 11/2006 Verghese et al.
2006/0269692 A1 11/2006 Balseanu
2006/0278524 A1 12/2006 Stowell
2007/0006806 A1 1/2007 Imai
2007/0010072 A1 1/2007 Bailey et al.
2007/0020953 A1 1/2007 Tsai et al.
2007/0022954 A1 2/2007 Iizuka et al.
2007/0028842 A1 2/2007 Inagawa et al.
2007/0031598 A1 2/2007 Okuyama et al.
2007/0031599 A1 2/2007 Gschwandtner et al.
2007/0032082 A1 2/2007 Ramaswamy et al.
2007/0037412 A1 2/2007 Dip et al.
2007/0042117 A1 2/2007 Kupurao et al.
2007/0049053 A1 3/2007 Mahajani
2007/0054499 A1 3/2007 Jang
2007/0059948 A1 3/2007 Metzner et al.
2007/0062453 A1 3/2007 Ishikawa
2007/0065578 A1 3/2007 McDougall
2007/0066010 A1 3/2007 Ando
2007/0066079 A1 3/2007 Kloster et al.
2007/0077355 A1 4/2007 Chacin et al.
2007/0082132 A1 4/2007 Shinriki
2007/0084405 A1 4/2007 Kim
2007/0096194 A1 5/2007 Streck et al.
2007/0098527 A1 5/2007 Hall et al.
2007/0107845 A1 5/2007 Ishizawa et al.
2007/0111545 A1 5/2007 Lee et al.
2007/0116873 A1 5/2007 Li et al.
2007/0123037 A1 5/2007 Lee et al.
2007/0125762 A1 6/2007 Cui et al.
2007/0128538 A1 6/2007 Fairbairn et al.
2007/0134942 A1 6/2007 Ahn et al.
2007/0146621 A1 6/2007 Yeom
2007/0148990 A1 6/2007 Deboer et al.
2007/0155138 A1 7/2007 Tomasini et al.
2007/0158026 A1 7/2007 Amikura
2007/0163440 A1 7/2007 Kim et al.
2007/0166457 A1 7/2007 Yamoto et al.
2007/0166966 A1 7/2007 Todd et al.
2007/0166999 A1 7/2007 Vaarstra
2007/0173071 A1 7/2007 Afzali-Ardakani et al.
2007/0175393 A1 8/2007 Nishimura et al.
2007/0175397 A1 8/2007 Tomiyasu et al.
2007/0186952 A1 8/2007 Honda et al.
2007/0207275 A1 9/2007 Nowak et al.
2007/0209590 A1 9/2007 Li
2007/0210890 A1 9/2007 Hsu et al.
2007/0215048 A1 9/2007 Suzuki et al.
2007/0218200 A1 9/2007 Suzuki et al.
2007/0218705 A1 9/2007 Matsuki et al.
2007/0224777 A1 9/2007 Hamelin
2007/0224833 A1 9/2007 Morisada et al.
2007/0232031 A1 10/2007 Singh et al.
2007/0232071 A1 10/2007 Balseanu et al.
2007/0232501 A1 10/2007 Tonomura
2007/0234955 A1 10/2007 Suzuki et al.
2007/0237697 A1 10/2007 Clark
2007/0241688 A1 10/2007 DeVancentis et al.
2007/0248767 A1 10/2007 Okura
2007/0249131 A1 10/2007 Allen et al.
2007/0251444 A1 11/2007 Gros-Jean et al.
2007/0252244 A1 11/2007 Srividya et al.
2007/0252532 A1 11/2007 DeVincentis et al.
2007/0264807 A1 11/2007 Leone et al.
2007/0275166 A1 11/2007 Thridandam et al.
2007/0277735 A1 12/2007 Mokhesi et al.
2007/0281496 A1 12/2007 Ingle et al.
2007/0298362 A1 12/2007 Rocha-Alvarez et al.
2008/0003824 A1 1/2008 Padhi et al.
2008/0003838 A1 1/2008 Haukka et al.
2008/0006208 A1 1/2008 Ueno et al.
2008/0023436 A1 1/2008 Gros-Jean et al.
2008/0026574 A1 1/2008 Brcka
2008/0026597 A1 1/2008 Munro et al.
2008/0029790 A1 2/2008 Ahn et al.
2008/0036354 A1 2/2008 Letz et al.
2008/0038485 A1 2/2008 Fukazawa et al.
2008/0054332 A1 3/2008 Kim et al.
2008/0054813 A1 3/2008 Espiau et al.
2008/0057659 A1 3/2008 Forbes et al.
2008/0061667 A1 3/2008 Gaertner et al.
2008/0066778 A1 3/2008 Matsushita et al.
2008/0069955 A1 3/2008 Hong et al.
2008/0075881 A1 3/2008 Won et al.
2008/0076266 A1 3/2008 Fukazawa et al.
2008/0081104 A1 4/2008 Hasebe et al.
2008/0081113 A1 4/2008 Clark
2008/0081121 A1 4/2008 Morita et al.
2008/0085226 A1 4/2008 Fondurulia et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2008/0092815 A1 4/2008 Chen et al.
2008/0113094 A1 5/2008 Casper
2008/0113096 A1 5/2008 Mahajani
2008/0113097 A1 5/2008 Mahajani et al.
2008/0124197 A1 5/2008 van der Meulen et al.
2008/0124908 A1 5/2008 Forbes et al.
2008/0124946 A1 5/2008 Xiao et al.
2008/0133154 A1 6/2008 Krauss et al.
2008/0149031 A1 6/2008 Chu et al.
2008/0152463 A1 6/2008 Chidambaram et al.
2008/0153311 A1 6/2008 Padhi et al.
2008/0173240 A1 7/2008 Furukawahara
2008/0173326 A1 7/2008 Gu et al.
2008/0176375 A1 7/2008 Erben et al.
2008/0178805 A1 7/2008 Paterson et al.
2008/0179715 A1 7/2008 Coppa
2008/0182075 A1 7/2008 Chopra
2008/0182390 A1 7/2008 Lemmi et al.
2008/0191193 A1 8/2008 Li et al.
2008/0199977 A1 8/2008 Weigel et al.
2008/0203487 A1 8/2008 Hohage et al.
2008/0211423 A1 9/2008 Shinmen et al.
2008/0211526 A1 9/2008 Shinma
2008/0216077 A1 9/2008 Emani et al.
2008/0220619 A1 9/2008 Matsushita et al.
2008/0224240 A1 9/2008 Ahn et al.
2008/0233288 A1 9/2008 Clark
2008/0237572 A1 10/2008 Chui et al.
2008/0241384 A1 10/2008 Jeong
2008/0242116 A1 10/2008 Clark
2008/0248310 A1 10/2008 Kim et al.
2008/0257494 A1 10/2008 Hayashi et al.
2008/0261413 A1 10/2008 Mahajani
2008/0264337 A1 10/2008 Sano et al.
2008/0267598 A1 10/2008 Nakamura
2008/0277715 A1 11/2008 Ohmi et al.
2008/0282970 A1 11/2008 Heys et al.
2008/0295872 A1 12/2008 Riker et al.
2008/0299326 A1 12/2008 Fukazawa
2008/0302303 A1 12/2008 Choi et al.
2008/0305246 A1 12/2008 Choi et al.
2008/0305443 A1 12/2008 Nakamura
2008/0315292 A1 12/2008 Ji et al.
2008/0317972 A1 12/2008 Hendriks
2009/0000550 A1 1/2009 Tran et al.
2009/0000551 A1 1/2009 Choi et al.
2009/0011608 A1 1/2009 Nabatame
2009/0020072 A1 1/2009 Mizunaga et al.
2009/0023229 A1 1/2009 Matsushita
2009/0029528 A1 1/2009 Sanchez et al.
2009/0029564 A1 1/2009 Yamashita et al.
2009/0033907 A1 2/2009 Watson
2009/0035947 A1 2/2009 Horii
2009/0041952 A1 2/2009 Yoon et al.
2009/0041984 A1 2/2009 Mayers et al.
2009/0045829 A1 2/2009 Awazu
2009/0050621 A1 2/2009 Awazu
2009/0061644 A1 3/2009 Chiang et al.
2009/0061647 A1 3/2009 Mallick et al.
2009/0085156 A1 4/2009 Dewey et al.
2009/0090382 A1 4/2009 Morisada
2009/0093094 A1 4/2009 Ye et al.
2009/0095221 A1 4/2009 Tam et al.
2009/0104789 A1 4/2009 Mallick et al.
2009/0107404 A1 4/2009 Ogliari et al.
2009/0120580 A1 5/2009 Kagoshima et al.
2009/0122293 A1 5/2009 Shibazaki
2009/0136668 A1 5/2009 Gregg et al.
2009/0136683 A1 5/2009 Fukasawa et al.
2009/0139657 A1 6/2009 Lee et al.
2009/0142935 A1 6/2009 Fukuzawa et al.
2009/0146322 A1 6/2009 Weling et al.
2009/0156015 A1 6/2009 Park et al.
2009/0209081 A1 8/2009 Matero
2009/0211523 A1 8/2009 Kuppurao et al.
2009/0211525 A1 8/2009 Sarigiannis et al.
2009/0239386 A1 9/2009 Suzaki et al.
2009/0242957 A1 10/2009 Ma et al.
2009/0246374 A1 10/2009 Vukovic
2009/0246399 A1 10/2009 Goundar
2009/0246971 A1 10/2009 Reid et al.
2009/0250955 A1 10/2009 Aoki
2009/0261331 A1 10/2009 Yang et al.
2009/0269506 A1 10/2009 Okura et al.
2009/0275205 A1 11/2009 Kiehlbauch et al.
2009/0277510 A1 11/2009 Shikata
2009/0283041 A1 11/2009 Tomiyasu et al.
2009/0283217 A1 11/2009 Lubomirsky et al.
2009/0286400 A1 11/2009 Heo et al.
2009/0286402 A1 11/2009 Xia et al.
2009/0289300 A1 11/2009 Sasaki et al.
2009/0304558 A1 12/2009 Patton
2009/0311857 A1 12/2009 Todd et al.
2010/0001409 A1 1/2010 Humbert et al.
2010/0006031 A1 1/2010 Choi et al.
2010/0014479 A1 1/2010 Kim
2010/0015813 A1 1/2010 McGinnis et al.
2010/0024727 A1 2/2010 Kim et al.
2010/0025796 A1 2/2010 Dabiran
2010/0040441 A1 2/2010 Obikane
2010/0041179 A1 2/2010 Lee
2010/0041243 A1 2/2010 Cheng et al.
2010/0055312 A1 3/2010 Kato et al.
2010/0055442 A1 3/2010 Kellock
2010/0075507 A1 3/2010 Chang et al.
2010/0089320 A1 4/2010 Kim
2010/0093187 A1 4/2010 Lee et al.
2010/0102417 A1 4/2010 Ganguli et al.
2010/0116209 A1 5/2010 Kato
2010/0124610 A1 5/2010 Aikawa et al.
2010/0124618 A1 5/2010 Kobayashi et al.
2010/0124621 A1 5/2010 Kobayashi et al.
2010/0126605 A1 5/2010 Stones
2010/0130017 A1 5/2010 Luo et al.
2010/0134023 A1 6/2010 Mills
2010/0136216 A1 6/2010 Tsuei et al.
2010/0140221 A1 6/2010 Kikuchi et al.
2010/0144162 A1 6/2010 Lee et al.
2010/0151206 A1 6/2010 Wu et al.
2010/0159638 A1 6/2010 Jeong
2010/0162752 A1 7/2010 Tabata et al.
2010/0170441 A1 7/2010 Won et al.
2010/0178137 A1 7/2010 Chintalapati et al.
2010/0178423 A1 7/2010 Shimizu et al.
2010/0184302 A1 7/2010 Lee et al.
2010/0193501 A1 8/2010 Zucker et al.
2010/0195392 A1 8/2010 Freeman
2010/0221452 A1 9/2010 Kang
2010/0230051 A1 9/2010 Iizuka
2010/0233886 A1 9/2010 Yang et al.
2010/0243166 A1 9/2010 Hayashi et al.
2010/0244688 A1 9/2010 Braun et al.
2010/0255198 A1 10/2010 Cleary et al.
2010/0255625 A1 10/2010 De Vries
2010/0259152 A1 10/2010 Yasuda et al.
2010/0270675 A1 10/2010 Harada
2010/0275846 A1 11/2010 Kitagawa
2010/0285319 A1 11/2010 Kwak et al.
2010/0294199 A1 11/2010 Tran et al.
2010/0301752 A1 12/2010 Bakre et al.
2010/0304047 A1 12/2010 Yang et al.
2010/0307415 A1 12/2010 Shero et al.
2010/0317198 A1 12/2010 Antonelli
2010/0322604 A1 12/2010 Fondurulia et al.
2011/0000619 A1 1/2011 Suh
2011/0006402 A1 1/2011 Zhou
2011/0006406 A1 1/2011 Urbanowicz et al.
2011/0014795 A1 1/2011 Lee
2011/0027999 A1 2/2011 Sparks et al.
2011/0034039 A1 2/2011 Liang et al.
2011/0048642 A1 3/2011 Mihara et al.
2011/0052833 A1 3/2011 Hanawa et al.
2011/0056513 A1 3/2011 Hombach et al.
2011/0056626 A1 3/2011 Brown et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2011/0061810 A1 3/2011 Ganguly et al.
2011/0070380 A1 3/2011 Shero et al.
2011/0081519 A1 4/2011 Dillingh
2011/0086516 A1 4/2011 Lee et al.
2011/0089469 A1 4/2011 Merckling
2011/0097901 A1 4/2011 Banna et al.
2011/0107512 A1 5/2011 Gilbert
2011/0108194 A1 5/2011 Yoshioka et al.
2011/0108741 A1 5/2011 Ingram
2011/0108929 A1 5/2011 Meng
2011/0117490 A1 5/2011 Bae et al.
2011/0117737 A1 5/2011 Agarwala et al.
2011/0124196 A1 5/2011 Lee
2011/0139748 A1 6/2011 Donnelly et al.
2011/0143032 A1 6/2011 Vrtis et al.
2011/0143461 A1 6/2011 Fish et al.
2011/0159202 A1 6/2011 Matsushita
2011/0159673 A1 6/2011 Hanawa et al.
2011/0175011 A1 7/2011 Ehrne et al.
2011/0183079 A1 7/2011 Jackson et al.
2011/0183269 A1 7/2011 Zhu
2011/0192820 A1 8/2011 Yeom et al.
2011/0198736 A1 8/2011 Shero et al.
2011/0210468 A1 9/2011 Shannon et al.
2011/0220874 A1 9/2011 Hanrath
2011/0236600 A1 9/2011 Fox et al.
2011/0239936 A1 10/2011 Suzaki et al.
2011/0254052 A1 10/2011 Kouvetakis
2011/0256675 A1 10/2011 Avouris
2011/0256726 A1 10/2011 Lavoie et al.
2011/0256727 A1 10/2011 Beynet et al.
2011/0256734 A1 10/2011 Hausmann et al.
2011/0265549 A1 11/2011 Cruse et al.
2011/0265951 A1 11/2011 Xu et al.
2011/0275166 A1 11/2011 Shero et al.
2011/0281417 A1 11/2011 Gordon et al.
2011/0283933 A1 11/2011 Makarov et al.
2011/0294075 A1 12/2011 Chen et al.
2011/0308460 A1 12/2011 Hong et al.
2012/0003500 A1 1/2012 Yoshida et al.
2012/0006489 A1 1/2012 Okita
2012/0024479 A1 2/2012 Palagashvili et al.
2012/0032311 A1 2/2012 Gates et al.
2012/0043556 A1 2/2012 Dube et al.
2012/0052681 A1 3/2012 Marsh
2012/0070136 A1 3/2012 Koelmel et al.
2012/0070997 A1 3/2012 Larson
2012/0090704 A1 4/2012 Laverdiere et al.
2012/0098107 A1 4/2012 Raisanen et al.
2012/0100464 A1 4/2012 Kageyama
2012/0103264 A1 5/2012 Choi et al.
2012/0103939 A1 5/2012 Wu et al.
2012/0107607 A1 5/2012 Takaki et al.
2012/0114877 A1 5/2012 Lee
2012/0121823 A1 5/2012 Chhabra
2012/0122302 A1 5/2012 Weidman et al.
2012/0128897 A1 5/2012 Xiao et al.
2012/0135145 A1 5/2012 Je et al.
2012/0156108 A1 6/2012 Fondurulia et al.
2012/0160172 A1 6/2012 Wamura et al.
2012/0164327 A1 6/2012 Sato
2012/0164837 A1 6/2012 Tan et al.
2012/0164842 A1 6/2012 Watanabe
2012/0171391 A1 7/2012 Won et al.
2012/0171874 A1 7/2012 Thridandam et al.
2012/0207456 A1 8/2012 Kim et al.
2012/0212121 A1 8/2012 Lin
2012/0214318 A1 8/2012 Fukazawa et al.
2012/0220139 A1 8/2012 Lee et al.
2012/0225561 A1 9/2012 Watanabe
2012/0240858 A1 9/2012 Taniyama et al.
2012/0263876 A1 10/2012 Haukka et al.
2012/0270339 A1 10/2012 Xie et al.
2012/0270393 A1 10/2012 Pore et al.
2012/0289053 A1 11/2012 Holland et al.
2012/0295427 A1 11/2012 Bauer
2012/0304935 A1 12/2012 Oosterlaken et al.
2012/0305196 A1 12/2012 Mori et al.
2012/0315113 A1 12/2012 Hiroki
2012/0318334 A1 12/2012 Bedell et al.
2012/0321786 A1 12/2012 Satitpunwaycha et al.
2012/0322252 A1 12/2012 Son et al.
2012/0325148 A1 12/2012 Yamagishi et al.
2012/0328780 A1 12/2012 Yamagishi et al.
2013/0005122 A1 1/2013 Schwarzenbach et al.
2013/0011983 A1 1/2013 Tsai
2013/0014697 A1 1/2013 Kanayama
2013/0014896 A1 1/2013 Shoji et al.
2013/0019944 A1 1/2013 Hekmatshoar-Tabai et al.
2013/0019945 A1 1/2013 Hekmatshoar-Tabai et al.
2013/0023129 A1 1/2013 Reed
2013/0048606 A1 2/2013 Mao et al.
2013/0064973 A1 3/2013 Chen et al.
2013/0068970 A1 3/2013 Matsushita
2013/0078392 A1 3/2013 Xiao et al.
2013/0081702 A1 4/2013 Mohammed et al.
2013/0084156 A1 4/2013 Shimamoto et al.
2013/0084714 A1 4/2013 Oka et al.
2013/0104988 A1 5/2013 Yednak et al.
2013/0104992 A1 5/2013 Yednak et al.
2013/0115383 A1 5/2013 Lu et al.
2013/0115763 A1 5/2013 Takamure et al.
2013/0122712 A1 5/2013 Kim et al.
2013/0126515 A1 5/2013 Shero et al.
2013/0129577 A1 5/2013 Halpin et al.
2013/0134148 A1 5/2013 Tachikawa
2013/0168354 A1 7/2013 Kanarik
2013/0180448 A1 7/2013 Sakaue et al.
2013/0183814 A1 7/2013 Huang et al.
2013/0210241 A1 8/2013 Lavoie et al.
2013/0217239 A1 8/2013 Mallick et al.
2013/0217240 A1 8/2013 Mallick et al.
2013/0217241 A1 8/2013 Underwood et al.
2013/0217243 A1 8/2013 Underwood et al.
2013/0224964 A1 8/2013 Fukazawa
2013/0230814 A1 9/2013 Dunn et al.
2013/0256838 A1 10/2013 Sanchez et al.
2013/0264659 A1 10/2013 Jung
2013/0288480 A1 10/2013 Sanchez et al.
2013/0292047 A1 11/2013 Tian et al.
2013/0292676 A1 11/2013 Milligan et al.
2013/0292807 A1 11/2013 Raisanen et al.
2013/0295779 A1 11/2013 Chandra et al.
2013/0319290 A1 12/2013 Xiao et al.
2013/0323435 A1 12/2013 Xiao et al.
2013/0330165 A1 12/2013 Wimplinger
2013/0330911 A1 12/2013 Huang et al.
2013/0330933 A1 12/2013 Fukazawa et al.
2013/0337583 A1 12/2013 Kobayashi et al.
2014/0000843 A1 1/2014 Dunn et al.
2014/0014642 A1 1/2014 Elliot et al.
2014/0014644 A1 1/2014 Akiba et al.
2014/0020619 A1 1/2014 Vincent et al.
2014/0027884 A1 1/2014 Tang et al.
2014/0033978 A1 2/2014 Adachi et al.
2014/0036274 A1 2/2014 Marquardt et al.
2014/0048765 A1 2/2014 Ma et al.
2014/0056679 A1 2/2014 Yamabe et al.
2014/0060147 A1 3/2014 Sarin et al.
2014/0062304 A1 3/2014 Nakano et al.
2014/0067110 A1 3/2014 Lawson et al.
2014/0073143 A1 3/2014 Alokozai et al.
2014/0077240 A1 3/2014 Roucka et al.
2014/0084341 A1 3/2014 Weeks
2014/0087544 A1 3/2014 Tolle
2014/0094027 A1 4/2014 Azumo et al.
2014/0096716 A1 4/2014 Chung et al.
2014/0099798 A1 4/2014 Tsuji
2014/0103145 A1 4/2014 White et al.
2014/0116335 A1 5/2014 Tsuji et al.
2014/0120487 A1 5/2014 Kaneko
2014/0127907 A1 5/2014 Yang
2014/0141625 A1 5/2014 Fukazawa et al.
2014/0159170 A1 6/2014 Raisanen et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2014/0174354	A1	6/2014	Arai
2014/0175054	A1	6/2014	Carlson et al.
2014/0182053	A1	7/2014	Huang
2014/0217065	A1	8/2014	Winkler et al.
2014/0220247	A1	8/2014	Haukka et al.
2014/0225065	A1	8/2014	Rachmady et al.
2014/0227072	A1	8/2014	Lee et al.
2014/0251953	A1	9/2014	Winkler et al.
2014/0251954	A1	9/2014	Winkler et al.
2014/0283747	A1	9/2014	Kasai et al.
2014/0346650	A1	11/2014	Raisanen et al.
2014/0349033	A1	11/2014	Nonaka et al.
2014/0363980	A1	12/2014	Kawamata et al.
2014/0363985	A1	12/2014	Jang et al.
2014/0367043	A1	12/2014	Bishara et al.
2015/0004316	A1	1/2015	Thompson et al.
2015/0004317	A1	1/2015	Dussarrat et al.
2015/0007770	A1	1/2015	Chandrasekharan et al.
2015/0014632	A1	1/2015	Kim et al.
2015/0021599	A1	1/2015	Ridgeway
2015/0024609	A1	1/2015	Milligan et al.
2015/0048485	A1	2/2015	Tolle
2015/0078874	A1	3/2015	Sansoni
2015/0086316	A1	3/2015	Greenberg
2015/0091057	A1	4/2015	Xie et al.
2015/0096973	A1	4/2015	Dunn et al.
2015/0099072	A1	4/2015	Takamure et al.
2015/0132212	A1	5/2015	Winkler et al.
2015/0140210	A1	5/2015	Jung et al.
2015/0147483	A1	5/2015	Fukazawa
2015/0147877	A1	5/2015	Jung
2015/0167159	A1	6/2015	Halpin et al.
2015/0170954	A1	6/2015	Agarwal
2015/0174768	A1	6/2015	Rodnick
2015/0184291	A1	7/2015	Alokozai et al.
2015/0187568	A1	7/2015	Pettinger et al.
2015/0217456	A1	8/2015	Tsuji et al.
2015/0240359	A1	8/2015	Jdira et al.
2015/0267295	A1	9/2015	Hill et al.
2015/0267297	A1	9/2015	Shiba
2015/0267299	A1	9/2015	Hawkins
2015/0267301	A1	9/2015	Hill et al.
2015/0284848	A1	10/2015	Nakano et al.
2015/0287626	A1	10/2015	Arai
2015/0308586	A1	10/2015	Shugrue et al.
2015/0315704	A1	11/2015	Nakano et al.
2016/0013024	A1	1/2016	Milligan et al.
2016/0024656	A1	1/2016	White et al.
2016/0051964	A1	2/2016	Tolle et al.

FOREIGN PATENT DOCUMENTS

CN	101522943	9/2009
CN	101423937	9/2011
DE	102008052750	6/2009
EP	2036600	3/2009
EP	2426233	7/2012
JP	03-044472	2/1991
JP	H04115531	4/1992
JP	06-53210	2/1994
JP	07-130731	5/1995
JP	07-034936	8/1995
JP	7-272694	10/1995
JP	H07283149	10/1995
JP	08-181135	7/1996
JP	H08335558	12/1996
JP	10-064696	3/1998
JP	10-0261620	9/1998
JP	2845163	1/1999
JP	2001-15698	1/2001
JP	2001342570	12/2001
JP	2004014952	1/2004
JP	2004091848	3/2004
JP	2004128019	4/2004
JP	2004134553	4/2004
JP	2004294638	10/2004
JP	2004310019	11/2004
JP	2004538374	12/2004
JP	2005507030	3/2005
JP	2006186271	7/2006
JP	3140111	3/2008
JP	2008060304	3/2008
JP	2008527748	7/2008
JP	2008202107	9/2008
JP	2009016815	1/2009
JP	2009099938	5/2009
JP	2010067940	3/2010
JP	2010097834	4/2010
JP	2010205967	9/2010
JP	2010251444	10/2010
JP	2012089837	5/2012
JP	2012146939	8/2012
KR	20100020834	2/2010
TW	I226380	1/2005
TW	200701301	1/2007
WO	9832893	7/1998
WO	2004008827	1/2004
WO	2004010467	1/2004
WO	2006054854	5/2006
WO	2006056091	6/2006
WO	2006101857	6/2006
WO	2006078666	7/2006
WO	2006080782	8/2006
WO	2007140376	12/2007
WO	2010039363	4/2010
WO	2010118051	1/2011
WO	2011019950	2/2011
WO	2013078065	5/2013
WO	2013078066	5/2013

OTHER PUBLICATIONS

USPTO; Office Action dated Feb. 15, 2011 in U.S. Appl. No. 12/118,596.

USPTO; Notice of Allowance dated Aug. 4, 2011 in U.S. Appl. No. 12/118,596.

USPTO; Non-Final Office Action dated Apr. 1, 2010 in U.S. Appl. No. 12/357,174.

USPTO; Final Office Action dated Sep. 1, 2010 in U.S. Appl. No. 12/357,174.

USPTO; Notice of Allowance dated Dec. 13, 2010 in U.S. Appl. No. 12/357,174.

USPTO; Non-Final Office Action dated Dec. 29, 2010 in U.S. Appl. No. 12/362,023.

USPTO; Non-Final Office Action dated Jul. 26, 2011 in U.S. Appl. No. 12/416,809.

USPTO; Final Office Action dated Dec. 6, 2011 in U.S. Appl. No. 12/416,809.

USPTO; Notice of Allowance dated Jun. 16, 2011 in U.S. Appl. No. 12/430,751.

USPTO; Notice of Allowance dated Jul. 27, 2011 in U.S. Appl. No. 12/430,751.

USPTO; Notice of Allowance dated Oct. 1, 2010 in U.S. Appl. No. 12/467,017.

USPTO; Non-Final Office Action dated Mar. 18, 2010 in U.S. Appl. No. 12/489,252.

USPTO; Notice of Allowance dated Sep. 2, 2010 in U.S. Appl. No. 12/489,252.

USPTO; Non-Final Office Action dated Dec. 15, 2010 in U.S. Appl. No. 12/553,759.

USPTO; Final Office Action dated May 4, 2011 in U.S. Appl. No. 12/553,759.

USPTO; Non-Final Office Action dated Sep. 6, 2011 in U.S. Appl. No. 12/553,759.

USPTO; Notice of Allowance dated Jan. 24, 2012 in U.S. Appl. No. 12/553,759.

USPTO; Non-Final Office Action dated Oct. 19, 2012 in U.S. Appl. No. 12/618,355.

USPTO; Final Office Action dated May 8, 2013 in U.S. Appl. No. 12/618,355.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO; Non-Final Office Action dated Apr. 8, 2015 in U.S. Appl. No. 12/618,355.
USPTO; Final Office Action dated Oct. 22, 2015 in U.S. Appl. No. 12/618,355.
USPTO; Non-Final Office Action dated Feb. 16, 2012 in U.S. Appl. No. 12/618,419.
USPTO; Final Office Action dated Jun. 22, 2012 in U.S. Appl. No. 12/618,419.
USPTO; Non-Final Office Action dated Nov. 27, 2012 in U.S. Appl. No. 12/618,419.
USPTO; Notice of Allowance dated Apr. 12, 2013 in U.S. Appl. No. 12/618,419.
USPTO; Non-Final Office Action dated Dec. 6, 2011 in U.S. Appl. No. 12/718,731.
USPTO; Notice of Allowance dated Mar. 16, 2012 in U.S. Appl. No. 12/718,731.
USPTO; Restriction Requirement dated Jan. 15, 2013 in U.S. Appl. No. 12/754,223.
USPTO; Office Action dated Feb. 26, 2013 in U.S. Appl. No. 12/754,223.
USPTO; Final Office Action dated Jun. 28, 2013 in U.S. Appl. No. 12/754,223.
USPTO; Office Action dated Feb. 25, 2014 in U.S. Appl. No. 12/754,223.
USPTO; Final Office Action dated Jul. 14, 2014 in U.S. Appl. No. 12/754,223.
USPTO; Non-Final Office Action dated Mar. 25, 2015 in U.S. Appl. No. 12/754,223.
USPTO; Final Office Action dated Aug. 12, 2015 in U.S. Appl. No. 12/754,223.
USPTO; Office Action dated Apr. 23, 2013 in U.S. Appl. No. 12/763,037.
USPTO; Final Office Action dated Oct. 21, 2013 in U.S. Appl. No. 12/763,037.
USPTO; Office Action dated Oct. 8, 2014 in U.S. Appl. No. 12/763,037.
USPTO; Notice of Allowance dated Jan. 27, 2015 in U.S. Appl. No. 12/763,037.
USPTO; Non-Final Office Action dated Jan. 24, 2011 in U.S. Appl. No. 12/778,808.
USPTO; Notice of Allowance dated May 9, 2011 in U.S. Appl. No. 12/778,808.
USPTO; Notice of Allowance dated Oct. 12, 2012 in U.S. Appl. No. 12/832,739.
USPTO; Non-Final Office Action dated Oct. 16, 2012 in U.S. Appl. No. 12/847,848.
USPTO; Final Office Action dated Apr. 22, 2013 in U.S. Appl. No. 12/847,848.
USPTO; Notice of Allowance dated Jan. 16, 2014 in U.S. Appl. No. 12/847,848.
USPTO; Restriction Requirement dated Sep. 25, 2012 in U.S. Appl. No. 12/854,818.
USPTO; Office Action dated Dec. 6, 2012 in U.S. Appl. No. 12/854,818.
USPTO; Final Office Action dated Mar. 13, 2013 in U.S. Appl. No. 12/854,818.
USPTO; Office Action dated Aug. 30, 2013 in U.S. Appl. No. 12/854,818.
USPTO; Final Office Action dated Mar. 26, 2014 in U.S. Appl. No. 12/854,818.
USPTO; Office Action dated Jun. 3, 2014 in U.S. Appl. No. 12/854,818.
USPTO; Non-Final Office Action dated Jul. 11, 2012 in U.S. Appl. No. 12/875,889.
USPTO; Notice of Allowance dated Jan. 4, 2013 in U.S. Appl. No. 12/875,889.
USPTO; Notice of Allowance dated Jan. 9, 2012 in U.S. Appl. No. 12/901,323.
USPTO; Non-Final Office Action dated Nov. 20, 2013 in U.S. Appl. No. 12/910,607.
USPTO; Final Office Action dated Apr. 28, 2014 in U.S. Appl. No. 12/910,607.
USPTO; Notice of Allowance dated Aug. 15, 2014 in U.S. Appl. No. 12/910,607.
USPTO; Non-Final Office Action dated Oct. 24, 2012 in U.S. Appl. No. 12/940,906.
USPTO; Final Office Action dated Feb. 13, 2013 in U.S. Appl. No. 12/940,906.
USPTO; Notice of Allowance dated Apr. 23, 2013 in U.S. Appl. No. 12/940,906.
USPTO; Non-Final Office Action dated Dec. 7, 2012 in U.S. Appl. No. 12/953,870.
USPTO; Final Office Action dated Apr. 22, 2013 in U.S. Appl. No. 12/953,870.
USPTO; Non-Final Office Action dated Sep. 19, 2012 in U.S. Appl. No. 13/016,735.
USPTO; Final Office Action dated Feb. 11, 2013 in U.S. Appl. No. 13/016,735.
USPTO; Notice of Allowance dated Apr. 24, 2013 in U.S. Appl. No. 13/016,735.
USPTO; Non-Final Office Action dated Apr. 4, 2012 in U.S. Appl. No. 13/030,438.
USPTO; Final Office Action dated Aug. 22, 2012 in U.S. Appl. No. 13/030,438.
USPTO; Notice of Allowance dated Oct. 24, 2012 in U.S. Appl. No. 13/030,438.
USPTO; Non-Final Office Action dated Dec. 3, 2012 in U.S. Appl. No. 13/040,013.
USPTO; Notice of Allowance dated May 3, 2013 in U.S. Appl. No. 13/040,013.
USPTO; Notice of Allowance dated Sep. 13, 2012 in U.S. Appl. No. 13/085,698.
USPTO; Non-Final Office Action dated Mar. 29, 2013 in U.S. Appl. No. 13/094,402.
USPTO; Final Office Action dated Jul. 17, 2013 in U.S. Appl. No. 13/094,402.
USPTO; Notice of Allowance dated Sep. 30, 2013 in U.S. Appl. No. 13/094,402.
USPTO; Restriction Requirement dated May 8, 2013 in U.S. Appl. No. 13/102,980.
USPTO; Office Action dated Oct. 7, 2013 in U.S. Appl. No. 13/102,980.
USPTO; Final Office Action dated Mar. 25, 2014 in U.S. Appl. No. 13/102,980.
USPTO; Notice of Allowance dated Jul. 3, 2014 in U.S. Appl. No. 13/102,980.
USPTO; Non-Final Office Action dated Jul. 17, 2014 in U.S. Appl. No. 13/154,271.
USPTO; Final Office Action dated Jan. 2, 2015 in U.S. Appl. No. 13/154,271.
USPTO; Non-Final Office Action dated May 27, 2015 in U.S. Appl. No. 13/154,271.
USPTO; Final Office Action dated Nov. 23, 2015 in U.S. Appl. No. 13/154,271.
USPTO; Notice of Allowance dated Feb. 10, 2016 in U.S. Appl. No. 13/154,271.
USPTO; Non-Final Office Action dated Oct. 27, 2014 in U.S. Appl. No. 13/169,951.
USPTO; Final Office Action dated May 26, 2015 in U.S. Appl. No. 13/169,591.
USPTO; Non-Final Office Action dated Sep. 1, 2015 in U.S. Appl. No. 13/169,951.
USPTO; Non-Final Office Action dated Jun. 24, 2014 in U.S. Appl. No. 13/181,407.
USPTO; Final Office Action dated Sep. 24, 2014 in U.S. Appl. No. 13/181,407.
USPTO; Non-Final Office Action dated Jan. 2, 2015 in U.S. Appl. No. 13/181,407.
USPTO; Final Office Action dated Apr. 8, 2015 in U.S. Appl. No. 13/181,407.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO; Non-Final Office Action dated Jan. 23, 2013 in U.S. Appl. No. 13/184,351.
USPTO; Final Office Action dated Jul. 29, 2013 in U.S. Appl. No. 13/184,351.
USPTO; Non-Final Office Action dated Jul. 16, 2014 in U.S. Appl. No. 13/184,351.
USPTO; Final Office Action dated Feb. 17, 2015 in U.S. Appl. No. 13/184,351.
USPTO; Non-Final Office Action dated Aug. 10, 2015 in U.S. Appl. No. 13/184,351.
USPTO; Non-Final Office Action dated Sep. 17, 2014 in U.S. Appl. No. 13/187,300.
USPTO; Final Office Action dated Apr. 15, 2015 in U.S. Appl. No. 13/187,300.
USPTO; Non-Final Office Action dated Apr. 7, 2016 in U.S. Appl. No. 13/187,300.
USPTO; Non-Final Office Action dated Oct. 1, 2012 in U.S. Appl. No. 13/191,762.
USPTO; Final Office Action dated Apr. 10, 2013 in U.S. Appl. No. 13/191,762.
USPTO; Notice of Allowance dated Aug. 15, 2013 in U.S. Appl. No. 13/191,762.
USPTO; Non-Final Office Action dated Oct. 22, 2012 in U.S. Appl. No. 13/238,960.
USPTO; Final Office Action dated May 3, 2013 in U.S. Appl. No. 13/238,960.
USPTO; Non-Final Office Action dated Apr. 26, 2013 in U.S. Appl. No. 13/250,721.
USPTO; Notice of Allowance dated Sep. 11, 2013 in U.S. Appl. No. 13/250,721.
USPTO; Non-Final Office Action dated Jul. 2, 2014 in U.S. Appl. No. 13/283,408.
USPTO; Final Office Action dated Jan. 29, 2015 in U.S. Appl. No. 13/283,408.
USPTO; Non-Final Office Action dated Jun. 17, 2015 in U.S. Appl. No. 13/283,408.
USPTO; Final Office Action dated Dec. 18, 2015 in U.S. Appl. No. 13/283,408.
USPTO; Notice of Allowance dated Mar. 28, 2016 in U.S. Appl. No. 13/283,408.
USPTO; Restriction Requirement dated Dec. 16, 2013 in U.S. Appl. No. 13/284,642.
USPTO; Restriction Requirement dated Apr. 21, 2014 in U.S. Appl. No. 13/284,642.
USPTO; Office Action dated Jul. 30, 2014 in U.S. Appl. No. 13/284,642.
USPTO; Notice of Allowance dated Feb. 11, 2015 in U.S. Appl. No. 13/284,642.
USPTO; Office Action dated Jan. 28, 2014 in U.S. Appl. No. 13/312,591.
USPTO; Final Office Action dated May 14, 2014 in U.S. Appl. No. 13/312,591.
USPTO; Non-Final Office Action dated Nov. 26, 2014 in U.S. Appl. No. 13/312,591.
USPTO; Final Office Action dated Mar. 20, 2015 in U.S. Appl. No. 13/312,591.
USPTO; Notice of Allowance dated May 14, 2015 in U.S. Appl. No. 13/312,591.
USPTO; Non-Final Office Action dated Apr. 9, 2014 in U.S. Appl. No. 13/333,420.
USPTO; Notice of Allowance dated Sep. 15, 2014 in U.S. Appl. No. 13/333,420.
USPTO; Office Action dated Jan. 10, 2013 in U.S. Appl. No. 13/339,609.
USPTO; Office Action dated Feb. 11, 2013 in U.S. Appl. No. 13/339,609.
USPTO; Final Office Action dated May 17, 2013 in U.S. Appl. No. 13/339,609.
USPTO; Office Action dated Aug. 29, 2013 in U.S. Appl. No. 13/339,609.
USPTO; Final Office Action dated Dec. 18, 2013 in U.S. Appl. No. 13/339,609.
USPTO; Notice of Allowance dated Apr. 7, 2014 in U.S. Appl. No. 13/339,609.
USPTO; Non-Final Office Action dated Oct. 10, 2012 in U.S. Appl. No. 13/406,791.
USPTO; Final Office Action dated Jan. 31, 2013 in U.S. Appl. No. 13/406,791.
USPTO; Non-Final Office Action dated Apr. 25, 2013 in U.S. Appl. No. 13/406,791.
USPTO; Final Office Action dated Aug. 23, 2013 in U.S. Appl. No. 13/406,791.
USPTO; Non-Final Office Action dated Dec. 4, 2013 in U.S. Appl. No. 13/406,791.
USPTO; Final Office Action dated Apr. 21, 2014 in U.S. Appl. No. 13/406,791.
USPTO; Non-Final Office Action dated Jan. 14, 2013 in U.S. Appl. No. 13/410,970.
USPTO; Notice of Allowance dated Feb. 14, 2013 in U.S. Appl. No. 13/410,970.
USPTO; Non-Final Office Action dated Feb. 13, 2014 in U.S. Appl. No. 13/411,271.
USPTO; Non-Final Office Action dated Jul. 31, 2014 in U.S. Appl. No. 13/411,271.
USPTO; Final Office Action dated Jan. 16, 2015 in U.S. Appl. No. 13/411,271.
USPTO; Notice of Allowance dated Oct. 6, 2015 in U.S. Appl. No. 13/411,271.
USPTO; Restriction Requirement dated Oct. 29, 2013 in U.S. Appl. No. 13/439,528.
USPTO; Office Action dated Feb. 4, 2014 in U.S. Appl. No. 13/439,528.
USPTO; Final Office Action dated Jul. 8, 2014 in U.S. Appl. No. 13/439,528.
USPTO; Notice of Allowance dated Oct. 21, 2014 in U.S. Appl. No. 13/439,528.
USPTO; Non-Final Office Action dated Apr. 11, 2013 in U.S. Appl. No. 13/450,368.
USPTO; Notice of Allowance dated Jul. 17, 2013 in U.S. Appl. No. 13/450,368.
USPTO; Office Action dated May 23, 2013 in U.S. Appl. No. 13/465,340.
USPTO; Final Office Action dated Oct. 30, 2013 in U.S. Appl. No. 13/465,340.
USPTO; Notice of Allowance dated Feb. 12, 2014 in U.S. Appl. No. 13/465,340.
USPTO; Non-Final Office Action dated Oct. 17, 2013 in U.S. Appl. No. 13/493,897.
USPTO; Notice of Allowance dated Mar. 20, 2014 in U.S. Appl. No. 13/493,897.
USPTO; Office Action dated Dec. 20, 2013 in U.S. Appl. No. 13/535,214.
USPTO; Final Office Action dated Jun. 18, 2014 in U.S. Appl. No. 13/535,214.
USPTO; Notice of Allowance dated Oct. 23, 2014 in U.S. Appl. No. 13/535,214.
USPTO; Non-Final Office Action dated Sep. 11, 2013 in U.S. Appl. No. 13/550,419.
USPTO; Final Office Action dated Jan. 27, 2014 in U.S. Appl. No. 13/550,419.
USPTO; Notice of Allowance dated May 29, 2014 in U.S. Appl. No. 13/550,419.
USPTO; Non-Final Office Action dated Aug. 8, 2014 in U.S. Appl. No. 13/563,066.
USPTO; Final Office Action dated Feb. 12, 2015 in U.S. Appl. No. 13/563,066.
USPTO; Notice of Allowance dated Jun. 12, 2015 in U.S. Appl. No. 13/563,066.
USPTO; Notice of Allowance dated Jul. 16, 2015 in U.S. Appl. No. 13/563,066.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO; Non-Final Office Action dated Nov. 7, 2013 in U.S. Appl. No. 13/565,564.
USPTO; Final Office Action dated Feb. 28, 2014 in U.S. Appl. No. 13/565,564.
USPTO; Non-Final Office Action dated Jul. 2, 2014 in U.S. Appl. No. 13/565,564.
USPTO; Notice of Allowance dated Nov. 3, 2014 in U.S. Appl. No. 13/565,564.
USPTO; Non-Final Office Action dated Aug. 30, 2013 in U.S. Appl. No. 13/570,067.
USPTO; Notice of Allowance dated Jan. 6, 2014 in U.S. Appl. No. 13/570,067.
USPTO; Non-Final Office Action dated Oct. 15, 2014 in U.S. Appl. No. 13/597,043.
USPTO; Final Office Action dated Mar. 13, 2015 in U.S. Appl. No. 13/597,043.
USPTO; USPTO; Notice of Allowance dated Aug. 28, 2015 in U.S. Appl. No. 13/597,043.
USPTO; Non-Final Office Action dated Feb. 12, 2015 in U.S. Appl. No. 13/597,108.
USPTO; Final Office Action dated Jun. 1, 2015 in U.S. Appl. No. 13/597,108.
USPTO; Non-Final Office Action dated Dec. 8, 2015 in U.S. Appl. No. 13/597,108.
USPTO; Notice of Allowance dated Mar. 27, 2014 in U.S. Appl. No. 13/604,498.
USPTO; Office Action dated Nov. 15, 2013 in U.S. Appl. No. 13/612,538.
USPTO; Office Action dated Jul. 10, 2014 in U.S. Appl. No. 13/612,538.
USPTO; Non-Final Office Action dated Apr. 15, 2015 in U.S. Appl. No. 13/646,403.
USPTO; Final Office Action dated Oct. 15, 2015 in U.S. Appl. No. 13/646,403.
USPTO; Notice of Allowance dated Feb. 2, 2016 in U.S. Appl. No. 13/646,403.
USPTO; Non-Final Office Action dated May 15, 2014 in U.S. Appl. No. 13/646,471.
USPTO; Final Office Action dated Aug. 18, 2014 in U.S. Appl. No. 13/646,471.
USPTO; Non-Final Office Action dated Dec. 16, 2014 in U.S. Appl. No. 13/646,471.
USPTO; Final Office Action dated Apr. 21, 2015 in U.S. Appl. No. 13/646,471.
USPTO; Non-Final Office Action dated Aug. 19, 2015 in U.S. Appl. No. 13/646,471.
USPTO; Final Office Action dated Jan. 22, 2016 in U.S. Appl. No. 13/646,471.
USPTO; Non-Final Office Action dated May 28, 2015 in U.S. Appl. No. 13/651,144.
USPTO; Final Office Action dated Nov. 19, 2015 in U.S. Appl. No. 13/651,144.
USPTO; Non-Final Office Action dated Nov. 19, 2015 in U.S. Appl. No. 14/659,437.
USPTO; Non-Final Office Action dated Jun. 18, 2015 in U.S. Appl. No. 13/665,366.
USPTO; Non-Final Office Action dated Apr. 3, 2015 in U.S. Appl. No. 13/677,133.
USPTO; Notice of Allowance dated Aug. 4, 2015 in U.S. Appl. No. 13/677,133.
USPTO; Office Action dated Jun. 2, 2014 in U.S. Appl. No. 13/677,151.
USPTO; Final Office Action dated Nov. 14, 2014 in U.S. Appl. No. 13/677,151.
USPTO; Notice of Allowance dated Feb. 26, 2015 in U.S. Appl. No. 13/677,151.
USPTO; Non-Final Office Action dated Aug. 20, 2013 in U.S. Appl. No. 13/679,502.
USPTO; Final Office Action dated Feb. 25, 2014 in U.S. Appl. No. 13/679,502.
USPTO; Notice of Allowance dated May 2, 2014 in U.S. Appl. No. 13/679,502.
USPTO; Non-Final Office Action dated Jul. 21, 2015 in U.S. Appl. No. 13/727,324.
USPTO; Final Office Action dated Jan. 22, 2016 in U.S. Appl. No. 13/727,324.
USPTO; Non-Final Office Action dated Oct. 24, 2013 in U.S. Appl. No. 13/749,878.
USPTO; Non-Final Office Action dated Jun. 18, 2014 in U.S. Appl. No. 13/749,878.
USPTO; Final Office Action dated Dec. 10, 2014 in U.S. Appl. No. 13/749,878.
USPTO; Notice of Allowance Mar. 13, 2015 dated in U.S. Appl. No. 13/749,878.
USPTO; Office Action dated Apr. 23, 2014 in U.S. Appl. No. 13/784,362.
USPTO; Notice of Allowance dated Aug. 13, 2014 in U.S. Appl. No. 13/784,362.
USPTO; Non-Final Office Action dated Dec. 19, 2013 in U.S. Appl. No. 13/784,388.
USPTO; Notice of Allowance dated Jun. 4, 2014 in U.S. Appl. No. 13/784,388.
USPTO; Restriction Requirement dated May 8, 2014 in U.S. Appl. No. 13/791,246.
USPTO; Non-Final Office Action dated Sep. 19, 2014 in U.S. Appl. No. 13/791,246.
USPTO; Final Office Action dated Mar. 25, 2015 in U.S. Appl. No. 13/791,246.
USPTO; Non-Final Office Action dated Oct. 26, 2015 in U.S. Appl. No. 13/791,246.
USPTO; Final Office Action dated Apr. 20, 2016 in U.S. Appl. No. 13/791,246.
USPTO; Non-Final Office Action dated Nov. 6, 2015 in U.S. Appl. No. 13/791,339.
USPTO; Final Office Action dated Apr. 12, 2016 in U.S. Appl. No. 13/791,339.
USPTO; Non-Final Office Action dated Mar. 21, 2014 in U.S. Appl. No. 13/799,708.
USPTO; Notice of Allowance dated Oct. 31, 2014 in U.S. Appl. No. 13/799,708.
USPTO; Restriction Requirement dated Jun. 26, 2014 in U.S. Appl. No. 13/874,708.
USPTO; Non-Final Office Action dated Oct. 9, 2014 in U.S. Appl. No. 13/874,708.
USPTO; Notice of Allowance dated Mar. 10, 2015 in U.S. Appl. No. 13/874,708.
USPTO; Notice of Allowance dated Apr. 10, 2014 in U.S. Appl. No. 13/901,341.
USPTO; Notice of Allowance dated Jun. 6, 2014 in U.S. Appl. No. 13/901,341.
USPTO; Non-Final Office Action dated Jan. 2, 2015 in U.S. Appl. No. 13/901,372.
USPTO; Final Office Action dated Apr. 16, 2015 in U.S. Appl. No. 13/901,372.
USPTO; Non-Final Office Action dated Jul. 8, 2015 in U.S. Appl. No. 13/901,400.
USPTO; Final Office Action dated Jan. 14, 2016 in U.S. Appl. No. 13/901,400.
USPTO; Notice of Allowance dated Aug. 5, 2015 in U.S. Appl. No. 13/901,372.
USPTO; Non-Final Office Action dated Apr. 24, 2014 in U.S. Appl. No. 13/912,666.
USPTO; Final Office Action dated Sep. 25, 2014 in U.S. Appl. No. 13/912,666.
USPTO; Non-Final Office Action dated Jan. 26, 2015 in U.S. Appl. No. 13/912,666.
USPTO; Notice of Allowance dated Jun. 25, 2015 in U.S. Appl. No. 13/912,666.
USPTO; Non-Final Office Action dated Dec. 16, 2014 in U.S. Appl. No. 13/915,732.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO; Final Office Action dated Apr. 10, 2015 in U.S. Appl. No. 13/915,732.
USPTO; Notice of Allowance dated Jun. 19, 2015 in U.S. Appl. No. 13/915,732.
USPTO; Notice of Allowance dated Mar. 17, 2015 in U.S. Appl. No. 13/923,197.
USPTO; Non-Final Office Action dated Sep. 12, 2014 in U.S. Appl. No. 13/941,134.
USPTO; Notice of Allowance dated Jan. 20, 2015 in U.S. Appl. No. 13/941,134.
USPTO; Restriction Requirement dated Apr. 30, 2015 in U.S. Appl. No. 13/941,216.
USPTO; Non-Final Office Action dated Jul. 30, 2015 in U.S. Appl. No. 13/941,216.
USPTO; Restriction Requirement dated Sep. 16, 2014 in U.S. Appl. No. 13/948,055.
USPTO; Non-Final Office Action dated Oct. 30, 2014 in U.S. Appl. No. 13/948,055.
USPTO; Non-Final Office Action dated Jun. 29, 2015 in U.S. Appl. No. 13/966,782.
USPTO; Final Office Action dated Jan. 4, 2016 in U.S. Appl. No. 13/966,782.
USPTO; Notice of Allowance dated Oct. 7, 2015 in U.S. Appl. No. 13/973,777.
USPTO; Non-Final Office Action dated Feb. 20, 2015 in U.S. Appl. No. 14/018,231.
USPTO; Notice of Allowance dated Jul. 20, 2015 in U.S. Appl. No. 14/018,231.
USPTO; Restriction Requirement Action dated Jan. 28, 2015 in U.S. Appl. No. 14/018,345.
USPTO; Non-Final Office Action dated Apr. 7, 2015 in U.S. Appl. No. 14/018,345.
USPTO; Final Office Action dated Sep. 14, 2015 in U.S. Appl. No. 14/018,345.
USPTO; Notice of Allowance dated Jan. 14, 2016 in U.S. Appl. No. 14/018,345.
USPTO; Notice of Allowance dated Mar. 17, 2016 in U.S. Appl. No. 14/018,345.
USPTO; Non-Final Office Action dated Mar. 26, 2015 in U.S. Appl. No. 14/031,982.
USPTO; Final Office Action dated Aug. 28, 2015 in U.S. Appl. No. 14/031,982.
USPTO; Notice of Allowance dated Nov. 17, 2015 in U.S. Appl. No. 14/031,982.
USPTO; Non-Final Office Action dated Apr. 28, 2015 in U.S. Appl. No. 14/040,196.
USPTO; Notice of Allowance dated Sep. 11, 2015 in U.S. Appl. No. 14/040,196.
USPTO; Non-Final Action dated Dec. 3, 2015 in U.S. Appl. No. 14/050,150.
USPTO; Non-Final Office Action dated Dec. 15, 2014 in U.S. Appl. No. 14/065,114.
USPTO; Final Office Action dated Jun. 19, 2015 in U.S. Appl. No. 14/065,114.
USPTO; Non-Final Office Action dated Oct. 7, 2015 in U.S. Appl. No. 14/065,114.
USPTO; Notice of Allowance dated Feb. 22, 2016 in U.S. Appl. No. 14/065,114.
USPTO; Non-Final Office Action dated Nov. 14, 2014 in U.S. Appl. No. 14/069,244.
USPTO; Notice of Allowance dated Mar. 25, 2015 in U.S. Appl. No. 14/069,244.
USPTO; Non-Final Office Action dated Sep. 9, 2015 in U.S. Appl. No. 14/090,750.
USPTO; Final Office Action dated Feb. 11, 2016 U.S. Appl. No. 14/090,750.
USPTO; Non-Final Office Action dated Mar. 19, 2015 in U.S. Appl. No. 14/079,302.
USPTO; Final Office Action dated Sep. 1, 2015 in U.S. Appl. No. 14/079,302.
USPTO; Non-Final Office Action dated Mar. 19, 2015 in U.S. Appl. No. 14/166,462.
USPTO; Notice of Allowance dated Sep. 3, 2015 in U.S. Appl. No. 14/166,462.
USPTO; Non-Final Office Action dated Nov. 17, 2015 in U.S. Appl. No. 14/172,220.
USPTO; Office Action dated May 29, 2014 in U.S. Appl. No. 14/183,187.
USPTO; Final Office Action dated Nov. 7, 2014 in U.S. Appl. No. 14/183,187.
USPTO; Non-Final Office Action dated Mar. 16, 2015 in U.S. Appl. No. 14/183,187.
USPTO; Final Office Action dated Jul. 10, 2015 in U.S. Appl. No. 14/183,187.
USPTO; Non-Final Office Action dated Jan. 11, 2016 in U.S. Appl. No. 14/188,760.
USPTO; Non-Final Office Action dated Oct. 8, 2015 in U.S. Appl. No. 14/218,374.
USPTO; Final Office Action dated Feb. 23, 2016 in U.S. Appl. No. 14/218,374.
USPTO; Non-Final Office Action dated Sep. 22, 2015 in U.S. Appl. No. 14/219,839.
USPTO; Non-Final Office Action dated Nov. 25, 2015 in U.S. Appl. No. 14/219,879.
USPTO; Final Office Action dated Mar. 25, 2016 in U.S. Appl. No. 14/219,839.
USPTO; Non-Final Office Action dated Sep. 18, 2015 in U.S. Appl. No. 14/244,689.
USPTO; Notice of Allowance dated Feb. 11, 2016 in U.S. Appl. No. 14/244,689.
USPTO; Non-Final Office Action dated Oct. 7, 2015 in U.S. Appl. No. 14/246,969.
USPTO; Non-Final Office Action dated Nov. 20, 2015 in U.S. Appl. No. 14/260,701.
USPTO; Non-Final Office Action dated Aug. 19, 2015 in U.S. Appl. No. 14/268,348.
USPTO; Non-Final Office Action dated Jan. 6, 2016 in U.S. Appl. No. 14/268,348.
USPTO; Non-Final Office Action dated Oct. 20, 2015 in U.S. Appl. No. 14/281,477.
USPTO; Notice of Allowance dated Feb. 23, 2016 in U.S. Appl. No. 14/327,134.
USPTO; Non-Final Office Action dated Feb. 12, 2015 in U.S. Appl. No. 14/457,058.
USPTO; Final Office Action dated Jul. 14, 2015 in U.S. Appl. No. 14/457,058.
USPTO; Non-Final Office Action dated Nov. 6, 2015 in U.S. Appl. No. 14/457,058.
USPTO; Non-Final Office Action dated Nov. 24, 2015 in U.S. Appl. No. 14/498,036.
USPTO; Final Office Action dated Apr. 5, 2016 in U.S. Appl. No. 14/498,036.
USPTO; Non-Final Office Action dated Apr. 10, 2015 in U.S. Appl. No. 14/505,290.
USPTO; Notice of Allowance dated Aug. 21, 2015 in U.S. Appl. No. 14/505,290.
USPTO; Non-Final Office Action dated Jan. 16, 2015 in U.S. Appl. No. 14/563,044.
USPTO; Final Office Action dated Jul. 16, 2015 in U.S. Appl. No. 14/563,044.
USPTO; Notice of Allowance dated Oct. 15, 2015 in U.S. Appl. No. 14/563,044.
USPTO; Notice of Allowance dated Dec. 2, 2015 in U.S. Appl. No. 14/563,044.
USPTO; Non-Final Office Action dated Oct. 1, 2015 in U.S. Appl. No. 14/571,126.
USPTO; Final Office Action dated Feb. 22, 2016 in U.S. Appl. No. 14/571,126.
USPTO; Non-Final Office Action dated Nov. 25, 2015 in U.S. Appl. No. 14/598,532.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO; Non-Final Office Action dated Jan. 15, 2016 in U.S. Appl. No. 14/606,364.
USPTO; Non-Final Office Action dated Mar. 3, 2016 in U.S. Appl. No. 14/622,603.
USPTO; Non-Final Office Action dated Mar. 21, 2016 in U.S. Appl. No. 14/659,152.
USPTO; Final Office Action dated Mar. 17, 2016 in U.S. Appl. No. 14/659,437.
USPTO;Notice of Allowance dated Mar. 25, 2016 in U.S. Appl. No. 14/693,138.
USPTO; Non-Final Office Action dated Mar. 30, 2016 in U.S. Appl. No. 14/808,979.
USPTO; Non-Final Office Action dated Mar. 22, 2016 in U.S. Appl. No. 14/987,420.
USPTO; Non-Final Office Action dated Mar. 16, 2015 in U.S. Appl. No. 29/447,298.
USPTO; Notice of Allowance dated Jul. 6, 2015 in U.S. Appl. No. 29/447,298.
USPTO; Notice of Allowance dated Nov. 26, 2014 in U.S. Appl. No. 29/481,301.
USPTO; Notice of Allowance dated Feb. 17, 2015 in U.S. Appl. No. 29/481,308.
USPTO; Notice of Allowance dated Jan. 12, 2015 in U.S. Appl. No. 29/481,312.
USPTO; Notice of Allowance dated Apr. 30, 2015 in U.S. Appl. No. 29/481,315.
USPTO; Notice of Allowance dated May 11, 2015 in U.S. Appl. No. 29/511,011.
USPTO; Notice of Allowance dated May 11, 2015 in U.S. Appl. No. 29/514,153.
USPTO; Notice of Allowance dated Dec. 14, 2015 in U.S. Appl. No. 29/514,264.
PCT; International Search report and Written Opinion dated Nov. 12, 2010 in Application No. PCT/US2010/030126.
PCT; International Preliminary Report on Patentability dated Oct. 11, 2011 Application No. PCT/US2010/030126.
PCT; International Search report and Written Opinion dated Jan. 20, 2011 in Application No. PCT/US2010/045368.
PCT; International Search report and Written Opinion dated Feb. 6, 2013 in Application No. PCT/US2012/065343.
PCT; International Search report and Written Opinion dated Feb. 13, 2013 in Application No. PCT/US2012/065347.
Chinese Patent Office; Office Action dated Jan. 10, 2013 in Application No. 201080015699.9.
Chinese Patent Office; Office Action dated Jan. 12, 2015 in Application No. 201080015699.9.
Chinese Patent Office; Office Action dated May 24, 2013 in Application No. 201080036764.6.
Chinese Patent Office; Office Action dated Jan. 2, 2014 in Application No. 201080036764.6.
Chinese Patent Office; Office Action dated Jul. 1, 2014 in Application No. 201080036764.6.
Chinese Patent Office; Office Action dated Feb. 8, 2014 in Application No. 201110155056.
Chinese Patent Office; Office Action dated Sep. 16, 2014 in Application No. 201110155056.
Chinese Patent Office; Office Action dated Feb. 9, 2015 in Application No. 201110155056.
Japanese Patent Office; Office Action dated Jan. 25, 2014 in Application No. 2012-504786.
Japanese Patent Office; Office Action dated Dec. 1, 2014 in Application No. 2012-504786.
Korean Patent Office; Office Action dated Dec. 10, 2015 in Application No. 10-2010-0028336.
Taiwan Patent Office; Office Action dated Jul. 4, 2014 in Application No. 099110511.
Taiwan Patent Office; Office Action dated Dec. 19, 2014 in Taiwan Application No. 099127063.
Bearzotti, et al., "Fast Humidity Response of a Metal Halide-Doped Novel Polymer," Sensors and Actuators B, 7, pp. 451-454, (1992).
Bhatnagar et al., "Copper Interconnect Advances to Meet Moore's Law Milestones," Solid State Technology, 52, 10 (2009).
Buriak, "Organometallic Chemistry on Silicon and Germanium Surfaces," Chemical Reviews, 102, 5 (2002).
Cant et al., "Chemisorption Sites on Porous Silica Glass and on Mixed-Oxide Catalysis," Can. J. Chem. 46, 1373 (1968).
Chang et al. "Small-Subthreshold-Swing and Low-Voltage Flexible Organic Thin-Film Transistors Which Use HfLaO as the Gate Dielectric," IEEE Electron Device Letters, 30, 2, IEEE Electron Device Society 133-135 (2009).
Chen et al., "A Self-Aligned Airgap Interconnect Scheme," IEEE International Interconnect Technology Conference, 1-3, 146-148 (2009).
Choi et al., "Improvement of Silicon Direct Bonding using Surfaces Activated by Hydrogen Plasma Treatment," Journal of the Korean Physical Society, 37, 6, 878-881 (2000).
Choi et al., "Low Temperature Formation of Silicon Oxide Thin Films by Atomic Layer Deposition Using NH3/O2 Plasma," ECS Solid State Letters, 2(12) 114-116 (2013).
Crowell, "Chemical methods of thin film deposition: Chemical vapor deposition, atomic layer deposition, and related technologies," Journal of Vacuum Science & Technology A 21.5, S88-S95 (2003).
Cui et al., "Impact of Reductive N2/H2 Plasma on Porous Low-Dielectric Constant SiCOH Thin Films," Journal of Applied Physics 97, 113302, 1-8 (2005).
Dingemans et al., "Comparison Between Aluminum Oxide Surface Passivation Films Deposited with Thermal Aid," Plasma Aid and Pecvd, 35th IEEE PVCS, Jun. 2010.
Drummond et al., "Hydrophobic Radiofrequency Plasma-Deposited Polymer Films. Dielectric Properties and Surface Forces," Colloids and Surfaces A, 129-130, 117-129 (2006).
Easley et al., "Thermal Isolation of Microchip Reaction Chambers for Rapid Non-Contact DNA Amplification," J. Micromech. Microeng. 17, 1758-1766 (2007).
Ge et al., "Carbon Nanotube-Based Synthetic Gecko Tapes," Department of Polymer Science, PNAS, 10792-10795 (2007).
George et al., "Atomic Layer Deposition: An Overview," Chem. Rev. 110, 111-131 (2010).
Grill et al., "The Effect of Plasma Chemistry on the Damage Induced Porous SiCOH Dielectrics," IBM Research Division, RC23683 (W0508-008), Materials Science, 1-19 (2005).
Gupta et al., "Conversion of Metal Carbides to Carbide Derived Carbon by Reactive Ion Etching in Halogen Gas," Proceedings of SPIE—The International Society for Optical Engineering and Nanotechnologies for Space Applications, ISSN: 0277-786X (2006).
Heo et al., "Structural Characterization of Nanoporous Low-Dielectric Constant SiCOH Films Using Organosilane Precursors," NSTI—Nanotech, vol. 4, 122-123 (2007).
H.J. Yun et al., "Comparison of Atomic Scale Etching of Poly-Si in Inductively Coupled Ar and He Plasmas," Korean Journal of Chemical Engineering, 24, 670-673 (2007).
Jung et al., "Double Patterning of Contact Array with Carbon Polymer," Proc. Of SPIE, 6924, 69240C, 1-10 (2008).
Katamreddy et al., "ALD and Characterization of Aluminum Oxide Deposited on Si(100) using Tris(diethylamino) Aluminum and Water Vapor," Journal of the Electrochemical Society, 153 (10) C701-C706 (2006).
Kim et al., "Passivation Effect on Low-k S/OC Dielectrics by H2 Plasma Treatment," Journal of the Korean Physical Society, 40, 1, 94-98 (2002).
Kim et al., "Characteristics of Low Tempemure High Quality Silicon Oxide by Plasma Enhanced Atomic Layer Deposition with In-Situ Plasma Densification Process," The Electrochemical Society, ECS Transactions, College of Information and Communication Engineerign, Sungkyunkwan University, 53(1), 321-329 (2013).
King, Plasma Enhanced Atomic Layer Deposition of SiNx: H and SiO2, J. Vac. Sci. Technol., A29(4) (2011).

(56) **References Cited**

OTHER PUBLICATIONS

Kobayshi et al. "Temperature Dependence of SiO2 Film Growth with Plasma-Enhanced Atomic Layer Deposition," International Journal on the Science and Technology of Condensed Matter, 520, 3994-3998, (2012).

Koo et al., "Characteristics of Al2O3 Thin Films Deposited Using Dimethylaluminum Isopropoxide and Trimethylaluminum Precursors by the Plasma-Enhanced Atomic-Layer Deposition Method," Journal of Physical Society, 48, 1, 131-136 (2006).

Koutsokeras et al. Texture and Microstructure Evolution in Single-Phase TixTal—xN Alloys of Rocksalt Structure. Journal of Applied Physics, 110, 043535-1-043535-6, (2011).

Krenek et al. "IR Laser CVD of Nanodisperse Ge—Si—Sn Alloys Obtained by Dielectric Breakdown of GeH4/SiH4/SnH4 Mixtures", NanoCon, Brno, Czech Republic, EU (2014).

Kurosawa et al., "Synthesis and Characterization of Plasma-Polymerized Hexamethyldisiloxane Films," Thin Solid Films, 506-507, 176-179 (2006).

Lieberman, et al., "Principles of Plasma Discharges and Materials Processing," Second Edition, 368-381.

Lim et al., "Low-Temperature Growth of SiO2 Films by Plasma-Enhanced Atomic Layer Deposition," ETRI Journal, 27 (1), 118-121 (2005).

Liu et al., "Research, Design, and Experimen of End Effector for Wafer Transfer Robot," Industrial Robot: An International Journal, 79-91 (2012).

Mackus et al., "Optical Emission Spectroscopy as a Tool for Studying Optimizing, and Monitoring Plasma-Assisted Atomic Layer Deposition Processes," Journal of Vacuum Science and Technology, 77-87 (2010).

Maeno, "Gecko Tape Using Carbon Nanotubes," Nitto Denko Gihou, 47, 48-51.

Maeng et al., "Electrical properties of atomic layer disposition Hf02 and Hf0xNy on Si Substrates with Various Crystal Orientations," Journal of the Electrochemical Society, 155, Department of Materials Science and Engineering, Pohang University of Science and Technology, H267-H271 (2008).

Marsik et al., "Effect of Ultraviolet Curing Wavelength on Low-k Dielectric Material Properties and Plasma Damage Resistance," Sciencedirect.com, 519, 11, 3619-3626 (2011).

Moeen, "Design, Modelling and Characterization of Si/SiGe Structures for IR Bolometer Applications," KTH Royal Institute of Technology. Information and Communication Technology, Department of Integrated Devices and Circuits, Stockholm Sweden (2015).

Morishige et al., "Thermal Desorption and Infrared Studies of Ammonia Amines and Pyridines Chemisorbed on Chromic Oxide," J.Chem. Soc., Faraday Trans. 1, 78, 2947-2957 (1982).

Mukai et al., "A Study of CD Budget in Spacer Patterning Technology," Proc. Of SPIE, 6924, 1-8 (2008).

Nogueira et al., "Production of Highly Hydrophobic Films Using Low Frequency and High Density Plasma," Revista Brasileira de Aplicacoes de Vacuo, 25(1), 45-53 (2006).

Novaro et al., "Theoretical Study on a Reaction Pathway of Ziegler-Natta-Type Catalysis," J. Chem. Phys. 68(5), 2337-2351 (1978).

Radamson et al.,"Growth of Sn-alloyed Group IV Materials for Photonic and Electronic Applications", Manufacturing Nano Structures, 5, 129-144.

Schmatz et al., "Unusual Isomerization Reactions in 1.3-Diaza-2-Silcyclopentanes," Organometallics, 23, 1180-1182 (2004).

Scientific and Technical Information Center EIC 2800 Search Report dated Feb. 16, 2012.

S.D. Athavale et al., "Realization of Atomic Layer Etching of Silicon", Journal of Vacuum Science and Technology B, 14, 3702-3705 (1996).

Shamma et al., "PDL Oxide Enabled Doubling," Proc. Of SPIE, 6924, 69240D, 1-10 (2008).

Varma, et al., "Effect of Metal Halides on Thermal, Mechanical, and Electrical Properties of Polypyromelitimide Films," Journal of Applied Polymer Science, 32, 3987-4000, (1986).

Wirths, et al, "SiGeSn Growth tudies Using Reduced Pressure Chemical Vapor Deposition Towards Optoeleconic Applications," This Soid Films, 557, 183-187 (2014).

Yun et al., "Behavior of Various Organosilicon Molecules in PECVD Processes for Hydrocarbon-Doped Silicon Oxide Films," Solid State Phenomena, 124-126, 347-350 (2007).

* cited by examiner

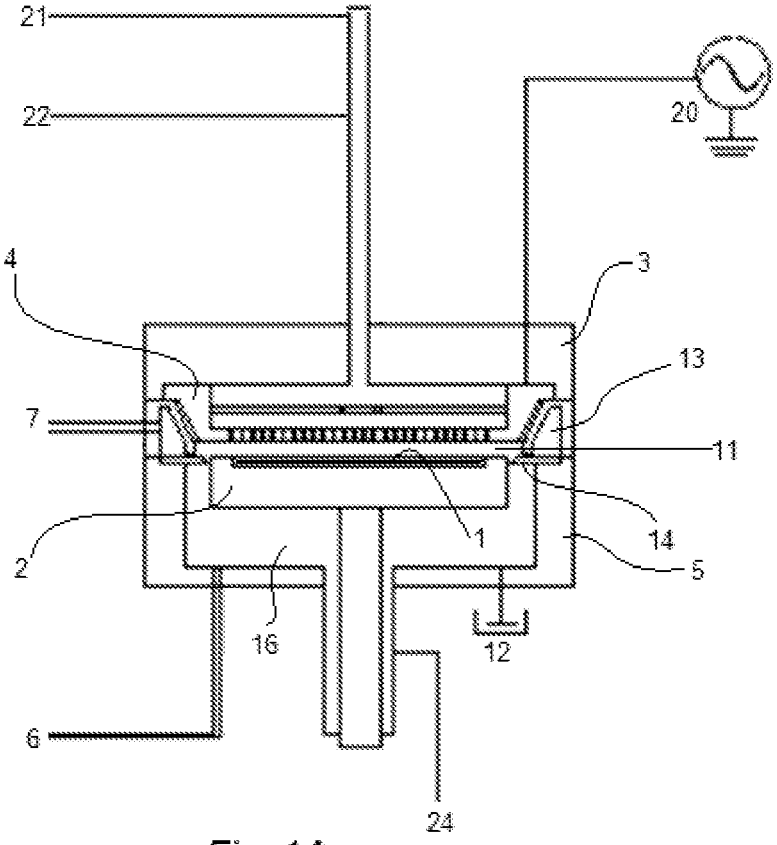


Fig. 1A

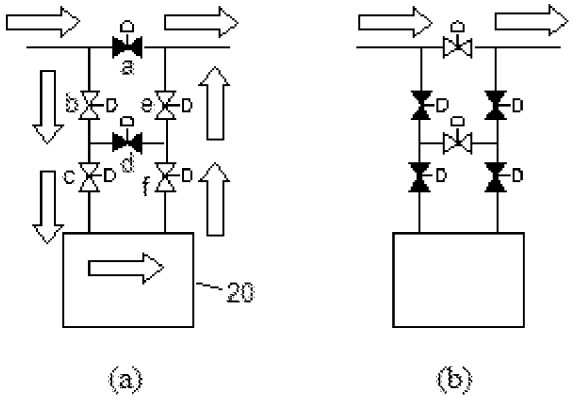
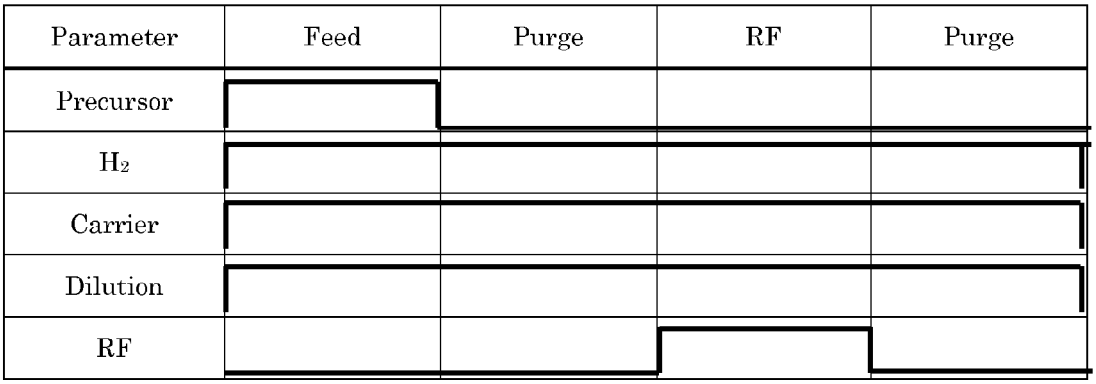


Fig. 1B

Fig. 2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Feed
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RF
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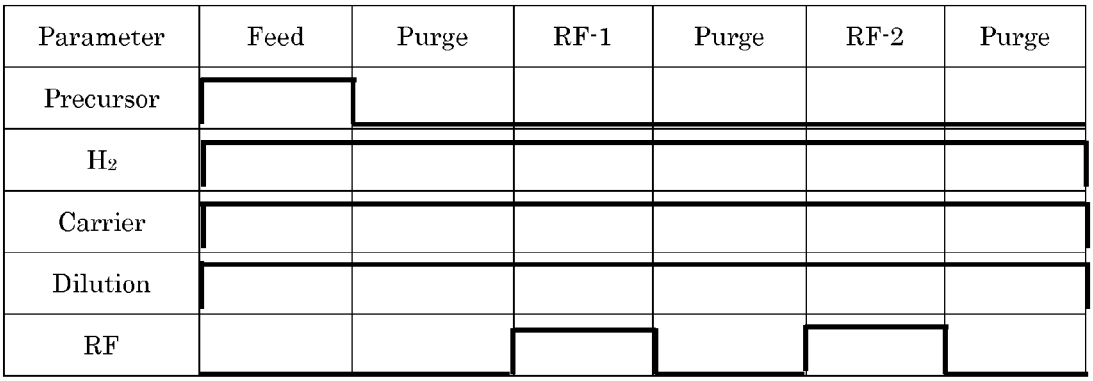
Precursor
H_2
Carrier
Dilution
RF

Fig. 3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Feed
Purge
RF-1
Purge
RF-2
Purge
Precursor
H_2
Carrier
Dilution
RF

METHOD FOR FORMING DIELECTRIC FILM IN TRENCHES BY PEALD USING H-CONTAINING GAS

BACKGROUND

1. Field of the Invention

The present invention generally relates to a method for depositing a dielectric film in a trench of a substrate by plasma-enhanced atomic layer deposition (PEALD). The present invention also relates to a method for increasing a sidewall coverage of a dielectric film deposited by PEALD.

2. Related Art

As a method of depositing a film having a good step coverage, atomic layer deposition (ALD) using chemisorption of a precursor is commonly performed. In this method, a film deposits more evenly in trenches of semiconductor circuits than does a film by CVD or the like. However, in plasma-enhanced atomic layer deposition (PEALD), since a sidewall of a trench of a substrate undergoes less ion bombardment than does a top surface of the substrate, surface reaction at the sidewall is less active than on the top surface, causing a problem that an etch rate of a film at the sidewall is different from (higher than) that on the top surface. In particular, when a precursor has an adsorption inhibition problem due to e.g., the presence of hydrocarbon components in the molecule of the precursor, the step coverage of a film deposited on a sidewall becomes low (e.g. 40% or less).

Conventionally, by increasing the process temperature or the like, the quality of a dielectric film (e.g., density, hardness) deposited on a sidewall is improved so that the etch rate at the sidewall can be decreased. However, the improvement is partial, and the problem in different etch rates between the sidewall and the top surface is not sufficiently resolved.

Any discussion of problems and solutions in relation to the related art has been included in this disclosure solely for the purposes of providing a context for the present invention, and should not be taken as an admission that any or all of the discussion was known at the time the invention was made.

SUMMARY

In some embodiments of the present invention, the thickness of film deposited on a target side of a trench of semiconductor circuits (substrate) can be controlled. In some embodiments, the thickness of film deposited on a sidewall of a trench relatively increases, i.e., the thickness of film deposited on a top (blanket) surface of the substrate relatively decreases. In one approach, the thickness of film on a sidewall of a trench can be controlled by controlling chemisorption of a precursor on a surface using a chemisorption-inhibitor gas to which the substrate is exposed as a preliminary treatment before depositing a film thereon, wherein functional groups exposed on the top surface of the substrate are terminated by Si—H bonds using a chemisorption-inhibitor gas such as hydrogen gas, thereby interfering with chemisorption of the precursor on the top surface and relatively increasing the deposition rate of film on the sidewall. In some embodiments of the present invention, another approach other than the above approach is taken, wherein when depositing a silicon-based dielectric film such as a SiC or SiN film by PEALD, a hydrogen-containing gas is used as a reactant gas so as to cause not only deposition of a film but also etching of the film by a plasma. Since more species excited by a plasma reach a flat surface, i.e., a top surface of a substrate and a bottom of a trench of the substrate, than excited species reaching a sidewall of the substrate, by controlling process parameters including feed quantity of a precursor and intensity and duration of a hydrogen plasma, controlling and balancing deposition and etching of film can be accomplished predominantly on a flat surface, whereby the thickness of film at the sidewall of the trench can be adjusted relative to the thickness of film on the flat surface of the substrate (the sidewall receives less effect of a plasma than does the flat surface). In the above, a film is being deposited by excited species of precursor while being etched by hydrogen and argon plasma, for example.

For purposes of summarizing aspects of the invention and the advantages achieved over the related art, certain objects and advantages of the invention are described in this disclosure. Of course, it is to be understood that not necessarily all such objects or advantages may be achieved in accordance with any particular embodiment of the invention. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

Further aspects, features and advantages of this invention will become apparent from the detailed description which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of this invention will now be described with reference to the drawings of preferred embodiments which are intended to illustrate and not to limit the invention. The drawings are greatly simplified for illustrative purposes and are not necessarily to scale.

FIG. **1**A is a schematic representation of a PEALD (plasma-enhanced atomic layer deposition) apparatus for depositing a dielectric film usable in an embodiment of the present invention.

FIG. **1**B illustrates a schematic representation of a precursor supply system using a flow-pass system (FPS) usable in an embodiment of the present invention.

FIG. **2** illustrates a PEALD process sequence according to an embodiment of the present invention.

FIG. **3** illustrates a PEALD process sequence according to another embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

In this disclosure, "gas" may include vaporized solid and/or liquid and may be constituted by a single gas or a mixture of gases. Likewise, an article "a" or "an" refers to a species or a genus including multiple species. In this disclosure, a process gas introduced to a reaction chamber through a showerhead may be comprised of, consist essentially of, or consist of a precursor and a reactant gas. The reactant gas may include a gas involving oxidizing and/or nitriding the precursor when RF power is applied to the reactant gas. The reactant gas can be introduced continuously to a reaction space if it is not reactive to the precursor without RF power. The precursor can be introduced with a carrier gas such as a noble gas. A gas other than the process gas, i.e., a gas introduced without passing through the showerhead, may be used for, e.g., sealing the reaction space, which includes a seal gas such as a noble gas. In some embodiments, "film" refers to a layer continuously extending in a direction perpendicular to a thickness direction

substantially without pinholes to cover an entire target or concerned surface, or simply a layer covering a target or concerned surface. In some embodiments, "layer" refers to a structure having a certain thickness formed on a surface or a synonym of film or a non-film structure. A film or layer may be constituted by a discrete single film or layer having certain characteristics or multiple films or layers, and a boundary between adjacent films or layers may or may not be clear and may be established based on physical, chemical, and/or any other characteristics, formation processes or sequence, and/or functions or purposes of the adjacent films or layers. Further, in this disclosure, any two numbers of a variable can constitute a workable range of the variable as the workable range can be determined based on routine work, and any ranges indicated may include or exclude the endpoints. Additionally, any values of variables indicated (regardless of whether they are indicated with "about" or not) may refer to precise values or approximate values and include equivalents, and may refer to average, median, representative, majority, etc. in some embodiments. The terms "constituted by" and "having" refer independently to "typically or broadly comprising", "comprising", "consisting essentially of", or "consisting of" in some embodiments.

In the present disclosure where conditions and/or structures are not specified, the skilled artisan in the art can readily provide such conditions and/or structures, in view of the present disclosure, as a matter of routine experimentation.

In all of the disclosed embodiments, any element used in an embodiment can be replaced with any elements equivalent thereto, including those explicitly, necessarily, or inherently disclosed herein, for the intended purposes. Further, the present invention can equally be applied to apparatuses and methods.

In this disclosure, any defined meanings do not necessarily exclude ordinary and customary meanings in some embodiments.

In some embodiments, the term "precursor" refers generally to a compound that participates in the chemical reaction that produces another compound, and particularly to a compound that constitutes a film matrix or a main skeleton of a film, whereas the term "reactant" refers to a compound that activates a precursor, modifies a precursor, or catalyzes a reaction of a precursor.

The dielectric film includes, but is not limited to, a low-k film constituted by a silicon carbide such as SiC, SiCN, and SiCON, a silicon oxide such as SiO, or a silicon nitride such as SiN, having a dielectric constant of about 3 to 6, typically about 3.5 to 4.5 In some embodiments, the dielectric film is formed in trenches, vias, or other recesses including side walls and bottom surfaces (collectively referred to as "trenches") by plasma-enhanced ALD or other plasma-assisted cyclic deposition methods. The trench may have a depth of about 10 nm to about 1,000 nm, typically about 100 nm to about 500 nm, and an aspect ratio of about 1 to about 10, typically about 2 to about 5 (e.g., a trench having a width of about 30 nm, a depth of about 110 nm, and an aspect ratio of about 4, formed as a pattern in a silicon substrate). The thickness of the deposited dielectric film may be in a range of about 2 nm to about 500 nm, typically about 10 nm to about 100 nm, more typically about 15 nm to about 30 nm (a desired film thickness can be selected as deemed appropriate according to the application and purpose of film, etc.).

The embodiments will be explained with respect to preferred embodiments. However, the present invention is not limited to the preferred embodiments.

In an embodiment, in a method for forming a dielectric film in a trench on a substrate by plasma-enhanced atomic layer deposition (PEALD) performing one or more process cycles, each process cycle comprises: (i) feeding a silicon-containing precursor in a pulse to a reaction space where the substrate is placed, said precursor being constituted by one or more hydrocarbon-containing compounds selected from the group consisting of: SiH_2R_2, $Si_2H_2R_4$, SiR_2X_2, Si_2R_6, SiH_3R, $Si_2H_4R_2$, SiH_2RX, $C_3H_6SiH_2$, $C_2H_4SiH_2$, $C_2H_4Si_2H_2$, $SiNHSiR_4H_2$, $SiNHSiR_6$, and $SiHX_2R$, wherein each X is independently chain or cyclic CxHy, and each R is independently chain or cyclic C_xH_y, cyclic $N_xC_yH_z$, $N(C_xH_y)_2$, $N(C_xH_y)H$, $O(C_xH_y)$, or OH, wherein x, y, and z are integers (e.g., x is an integer of 1 to 5, y is an integer of 1 to 10, and z is an integer of 3 to 15); (ii) supplying a hydrogen-containing reactant gas to the reaction space at a flow rate of more than about 30 sccm but less than about 800 sccm (e.g., about 50 sccm to about 500 sccm) in the absence of nitrogen-containing gas; (iii) supplying a noble gas to the reaction space; and (iv) applying RF power to the reaction space in the presence of the hydrogen-containing reactant gas and the noble gas and in the absence of any precursor in the reaction space, to form a monolayer constituting a dielectric film on a substrate at a growth rate of less than one atomic layer thickness per cycle. The growth rate per cycle or thickness of a monolayer refers to an average growth rate per cycle calculated based on the measured thickness of a deposited film and the number of cycles performed for the deposited film, or based on the total growth rate of the resultant deposited dielectric film. The one atomic layer thickness refers to a theoretical thickness of one atomic layer formed from a precursor gas without considering lamination or the interface between monolayers. The term "monolayer" refers to a layer formed by one process cycle of PEALD, which may not be a continuous film.

In some embodiments, the growth rate of the monolayer is less than about 0.1 nm per cycle (e.g., about 0.003 nm to about 0.09 nm). In general, the theoretical one atomic layer thickness is about 0.1 nm to about 0.5 nm, typically about 0.2 nm to about 0.3 nm. When the above-mentioned hydrocarbon-containing compound is used as a precursor, due to adsorption inhibition of the precursor by the hydrocarbon components on a substrate surface, the average growth rate of the film per cycle on a flat horizontal surface (a blanket surface) becomes less than one atomic layer thickness. In that case, in general, the growth rate of the monolayer on a sidewall is even worse than that on the blanket surface, resulting in a low step coverage on the sidewall (e.g., 40% or less). However, according to some embodiments of the present invention disclosed herein, the step coverage on the sidewall can surprisingly be increased to 80% or higher.

In some embodiments, the precursor has a chemical formula where at least one of X or R is an unsaturated hydrocarbon having, e.g., a carbon double or triple bond. In general, when the precursor includes more carbon atoms in its molecule, i.e., including fewer hydrogen atoms, more deposition of film takes place, rather than etching of film. In some embodiments, the precursor has a cyclic structure. In some embodiments, the precursor is one or more compounds selected from the group consisting of: SiH_2R_2 such as dimethylsilane, divinylsilane, and dipyridylsilane; $Si_2H_2R_4$ such as tertamethyldisilane; SiR_2X_2 such as divinyldimethylsilane and dimethyldipyridylsilane; Si_2R_6 such as hexamethydisilane; SiH_3R such as silylacetylene and allylsilane; $Si_2H_4R_2$ such as divinyldisilane and dimethyldisilane; SiH_2RX such as viylmethylsilane; $C_3H_6SiH_2$ such as silacyclobutane; silacycloethane; disilacycloethane;

$SiNHSiR_4H_2$ such as tetramethyldisilazane; $SiNHSiR_6$ such as hexamethyldisilazane; and $SiHX_2R$ such as dimethylpridyldisilane.

In some embodiments, the reactant gas is hydrogen gas. In some embodiments, the reactant gas is a hydrocarbon gas such as hexane In some embodiments, the noble gas is argon. A combination of H_2 and Ar is most effective in counteracting deposition of film, wherein H_2 in a plasma state likely causes chemical etching whereas Ar in a plasma state likely causes physical spattering (bombardment at an angle of about 45°) on the surface of a substrate. Thus, H_2 in a plasma state is effective to etch predominantly a film on a flat surface, whereas Ar in a plasma state is effective to etch rather uniformly a film on the flat surface and a film at the sidewall. Unlike Ar, He in a plasma state does not likely cause physical spattering, and thus, a combination of H_2 and Ar, rather than a combination of H_2 and He, is used in some embodiments.

In some embodiments, a ratio of flow rate of the noble gas, typically Ar, to flow rate of the hydrogen-containing reactant, typically hydrogen gas, is about 5:1 to about 100:1, preferably about 10:1 to about 60:1. In the above, the flow rate of the noble gas includes a carrier gas for carrying a precursor in addition to a dilution gas. When the flow rate of the hydrogen-containing reactant, typically hydrogen gas, is too low, etching effect is not sufficient to control growth rate of film on a flat surface, whereas when the flow rate is too high, etching effect is predominant and no film is deposited on the flat surface.

When a hydrogen plasma is used, both the etching effect and the deposition effect can be obtained, and can be balanced by adjusting the flow rate of hydrogen, the number of RF pulses per cycle, the feed of a precursor, etc. The etching by a hydrogen plasma may occur as follows, for example:

$$SiO_2+4H\text{—}Si+2H_2O, SiO_2+2H \rightarrow Si+H_2O_2$$

$$Si+xH \rightarrow SiH_x$$

On the other hand, deposition by a hydrogen plasma may occur via removing a ligand which promotes chemisorption, and via formation of dangling bonds. Further, deposition may occur through re-deposition of dissociated components by etching.

In some embodiments, in step (iii), the noble gas is supplied to the reaction space at a flow rate of about 1,000 sccm to about 5,000 sccm, preferably about 2,000 sccm to about 4,000 sccm.

In some embodiments, the reactant gas is supplied continuously to the reaction space throughout each process cycle. In some embodiments, the noble gas is continuously supplied to the reaction space throughout the process cycle.

In some embodiments, in step (iv), no gas other than the reactant gas and the noble gas is supplied to the reaction space.

In some embodiments, in step (i), the precursor is fed in an amount of about 0.00002 g/cycle to about 0.01 g/cycle and in a pulse having a duration of about 0.1 seconds to about 1.0 seconds. Since ALD is a self-limiting adsorption reaction process, the number of deposited precursor molecules is determined by the number of reactive surface sites and is independent of the precursor exposure after saturation, and a supply of the precursor is such that the reactive surface sites are saturated thereby per cycle. In other embodiments the plasma may be generated remotely and provided to the reaction chamber. The feed amount of precursor can be determined depending on the molecular weight of precursor.

In some embodiments, each process cycle further comprises a purging step between steps (i) and (iv), and between steps (iv) and (i) if the process cycle is repeated. In some embodiments, in step (iv), RF power is applied to the reaction space in two occurrences between which a purging step is conducted (in some embodiments, three or more occurrences per cycle). In some embodiments, in step (iv), RF power applied to the reaction space is about 0.028 W/cm^2 to about 0.28 W/cm^2, preferably 0.07 W/cm^2 to about 0.21 W/cm^2. When a combination of H_2 and Ar is used as a reactant gas, etching can occur at a low RF power. In some embodiments, the duration of a pulse of RF power is about 0.2 seconds to about 5 seconds, preferably about 0.5 seconds to about 1 second. The longer the duration of a pulse of RF power, the greater the reduction of thickness becomes. If application of RF power is divided into multiple sessions, the reduction of thickness can significantly be lowered. By adjusting the duration of RF power application and the number of RF power applications per cycle, the step coverage at the sidewall and on the flat surface can be desirably adjusted.

In some embodiments, the temperature during the process cycle is about 50° C. to about 500° C., preferably about 100° C. to about 300° C.

In some embodiments, the dielectric film is a film of SiC, SiCN, SiN, SiOCN, or SiO. For example, a SiN film can be deposited when a precursor having a Si—N bond such as silylamine compounds or aminosilane compounds is used, whereas a SiO film can be deposited when a precursor having a Si—O bond such as alkoxide compounds is used, even when only hydrogen gas and argon gas are used as a reactant gas.

In some embodiments, a sidewall coverage of the deposited dielectric film is about 80% or higher, typically about 80% to about 130%, wherein the sidewall coverage is defined as a ratio of thickness of film on a sidewall of the trench to thickness of film on a blanket surface of the trench.

In some embodiments, a method for increasing a sidewall coverage of a dielectric film deposited according to any deposition method disclosed herein is provided, wherein in step (i), the precursor is fed in a pulse having a first duration, in step (ii), the reactant gas is supplied at a first flow rate, and in step (iv), RF power is applied in a pulse having a first duration, and the dielectric film has a first sidewall coverage, said sidewall coverage being defined as a ratio of thickness of film on a sidewall of the trench to thickness of film on a blanket surface of the substrate, said method comprising: (a) setting a second duration of the pulse of the precursor in step (i), a second flow rate of the reactant gas in step (ii), and a second duration of the pulse of RF power in step (iv), wherein at least one of the second flow rate of the reactant gas and the second duration of the pulse of RF power is higher than the first flow rate of the reactant gas and the first duration of the pulse of RF power, respectively, and/or the second duration of the pulse of the precursor is shorter than the first duration of the pulse of the precursor; and (b) repeating steps (i) to (iv) using the second flow rate of the reactant gas and the second duration of the pulse of RF power, thereby depositing a dielectric film having a second sidewall coverage which is higher than the first sidewall coverage.

In some embodiments, the film is deposited by PEALD under conditions shown in Table 1 below.

TABLE 1

(the numbers are approximate)
Conditions for Deposition Cycle

Substrate temperature	50 to 500° C. (preferably 100 to 400° C.)
Pressure	100 to 1000 Pa (preferably 200 to 500 Pa)
Precursor pulse	0.1 to 3 Sec (preferably 0.1 to 1 Sec)
Precursor purge	0.3 to 10 Sec
Flow rate of reactant (continuous)	50 to 1000 sccm (preferably 100 to 300 sccm)
Carrier gas	e.g., argon
Dilution gas	e.g., argon
Flow rate of carrier/ dilution gas (continuous)	1000 to 5000 sccm (preferably 2000 to 4000 sccm)
RF power (13.56 MHz) for a 300-mm wafer	50 to 200 W (preferably 50 to 150 W)
RF power pulse (total)	0.2 to 5 sec (preferably 0.5 to 1 sec)
Purge	0.1 to 2 Sec
Growth rate per cycle	0.005 to 0.08 nm/cycle
Total thickness [nm]	3 to 20 Nm

FIG. **2** illustrates a PEALD process sequence according to an embodiment of the present invention. In this disclosure, the width of each column does not necessarily represent the actual time length, and a raised level of the line in each row represents an ON-state whereas a bottom level of the line in each row represents an OFF-state. The deposition cycle includes steps of feeding a precursor to a reaction zone, purging the reaction zone, applying RF power to the reaction zone, and purging the reaction zone in this order, wherein a purge/carrier gas is supplied continuously to the reaction zone throughout the entire steps of the deposition cycle, and a reactant gas for deposition is supplied continuously to the reaction zone throughout the entire steps of the deposition cycle. In the deposition cycle, steps of feeding the precursor, purging the reaction zone, applying RF power to the reaction zone, and purging the reaction zone can be repeated p times (p is an integer of 5 to 100, typically 8 to 50), depending on the target compositions and quality of the film, although repeating is not required.

In this disclosure, the word "continuously" refers to at least one of the following: without breaking a vacuum, without being exposed to air, without opening a chamber, as an in-situ process, without interruption as a step in sequence, and without changing main process conditions, depending on the embodiment. In some embodiments, an auxiliary step such as a delay between steps or other step immaterial or insubstantial in the context does not count as a step, and thus, the word "continuously" does not exclude an intervening auxiliary step.

FIG. **3** illustrates a PEALD process sequence according to another embodiment of the present invention. In this sequence, after the sequence illustrated in FIG. **2**, the deposition cycle further includes steps of applying again RF power ("RF-2") to the reaction zone, and purging the reaction zone in this order. In other words, application of RF power illustrated in FIG. **2** is divided into two sessions, i.e., the application of RF power comprises a first application of RF power, purging, and a second application of RF power. In some embodiments, the application of RF power may comprise more than two applications of RF power (e.g., three or four sessions). The first application and the subsequent application of RF power can be conducted in the same manner or in different manners, e.g., at different pulse durations (the first duration is shorter or longer than the second duration), different intensities (the first intensity is lower or higher than the second intensity), etc.

In the sequence illustrated in FIG. **2**, the precursor is supplied in a pulse using a carrier gas which is continuously supplied. This can be accomplished using a flow-pass system (FPS) wherein a carrier gas line is provided with a detour line having a precursor reservoir (bottle), and the main line and the detour line are switched, wherein when only a carrier gas is intended to be fed to a reaction chamber, the detour line is closed, whereas when both the carrier gas and a precursor gas are intended to be fed to the reaction chamber, the main line is closed and the carrier gas flows through the detour line and flows out from the bottle together with the precursor gas. In this way, the carrier gas can continuously flow into the reaction chamber, and can carry the precursor gas in pulses by switching the main line and the detour line. FIG. **1**B illustrates a precursor supply system using a flow-pass system (FPS) according to an embodiment of the present invention (black valves indicate that the valves are closed). As shown in (a) in FIG. **1**B, when feeding a precursor to a reaction chamber (not shown), first, a carrier gas such as Ar (or He) flows through a gas line with valves b and c, and then enters a bottle (reservoir) **20**. The carrier gas flows out from the bottle **20** while carrying a precursor gas in an amount corresponding to a vapor pressure inside the bottle **20**, and flows through a gas line with valves f and e, and is then fed to the reaction chamber together with the precursor. In the above, valves a and d are closed. When feeding only the carrier gas (noble gas) to the reaction chamber, as shown in (b) in FIG. **1**B, the carrier gas flows through the gas line with the valve a while bypassing the bottle **20**. In the above, valves b, c, e, and f are closed.

The precursor may be provided with the aid of a carrier gas. Since ALD is a self-limiting adsorption reaction process, the number of deposited precursor molecules is determined by the number of reactive surface sites and is independent of the precursor exposure after saturation, and a supply of the precursor is such that the reactive surface sites are saturated thereby per cycle. A plasma for deposition may be generated in situ, for example, in an ammonia gas that flows continuously throughout the deposition cycle. In other embodiments the plasma may be generated remotely and provided to the reaction chamber.

As mentioned above, each pulse or phase of each deposition cycle is preferably self-limiting. An excess of reactants is supplied in each phase to saturate the susceptible structure surfaces. Surface saturation ensures reactant occupation of all available reactive sites (subject, for example, to physical size or "steric hindrance" restraints) and thus ensures excellent step coverage. In some embodiments the pulse time of one or more of the reactants can be reduced such that complete saturation is not achieved and less than a monolayer is adsorbed on the substrate surface.

The process cycle can be performed using any suitable apparatus including an apparatus illustrated in FIG. **1**A, for example. FIG. **1**A is a schematic view of a PEALD apparatus, desirably in conjunction with controls programmed to conduct the sequences described herein, usable in some embodiments of the present invention. In this figure, by providing a pair of electrically conductive flat-plate electrodes **4**, **2** in parallel and facing each other in the interior **11** (reaction zone) of a reaction chamber **3**, applying HRF power (13.56 MHz or 27 MHz) **20** to one side, and electrically grounding the other side **12**, a plasma is excited between the electrodes. A temperature regulator is provided in a lower stage **2** (the lower electrode), and a temperature of a placed thereon is kept constant at a given temperature. The upper electrode **4** serves as a shower plate as well, and reactant gas (and noble gas) and precursor gas are introduced into the reaction chamber **3** through a gas line **21** and a gas line **22**, respectively, and through the shower plate **4**.

Additionally, in the reaction chamber **3**, a circular duct **13** with an exhaust line **7** is provided, through which gas in the interior **11** of the reaction chamber **3** is exhausted. Additionally, a transfer chamber **5** disposed below the reaction chamber **3** is provided with a seal gas line **24** to introduce seal gas into the interior **11** of the reaction chamber **3** via the interior **16** (transfer zone) of the transfer chamber **5** wherein a separation plate **14** for separating the reaction zone and the transfer zone is provided (a gate valve through which a wafer is transferred into or from the transfer chamber **5** is omitted from this figure). The transfer chamber is also provided with an exhaust line **6**. In some embodiments, the deposition of multi-element film and surface treatment are performed in the same reaction space, so that all the steps can continuously be conducted without exposing the substrate to air or other oxygen-containing atmosphere. In some embodiments, a remote plasma unit can be used for exciting a gas.

In some embodiments, in the apparatus depicted in FIG. **1**A, the system of switching flow of an inactive gas and flow of a precursor gas illustrated in FIG. **1**B (described earlier) can be used to introduce the precursor gas in pulses without substantially fluctuating pressure of the reaction chamber.

In some embodiments, a dual chamber reactor (two sections or compartments for processing wafers disposed closely to each other) can be used, wherein a reactant gas and a noble gas can be supplied through a shared line whereas a precursor gas is supplied through unshared lines.

A skilled artisan will appreciate that the apparatus includes one or more controller(s) (not shown) programmed or otherwise configured to cause the deposition and reactor cleaning processes described elsewhere herein to be conducted. The controller(s) are communicated with the various power sources, heating systems, pumps, robotics, and gas flow controllers or valves of the reactor, as will be appreciated by the skilled artisan.

The present invention is further explained with reference to working examples below. However, the examples are not intended to limit the present invention. In the examples where conditions and/or structures are not specified, the skilled artisan in the art can readily provide such conditions and/or structures, in view of the present disclosure, as a matter of routine experimentation. Also, the numbers applied in the specific examples can be modified by a range of at least ±50% in some embodiments, and the numbers are approximate.

EXAMPLES

A silicon carbide film was formed on a Si substrate (0300 mm) having trenches with an aspect ratio of 3.5 (a width of 30 nm, and a depth of 110 nm) by PEALD using a sequence illustrated in FIG. **2** or **3**, one cycle of which was conducted under the common conditions shown in Table 2 (process cycle) below using the PEALD apparatus illustrated in FIG. **1**A and a gas supply system (FPS) illustrated in FIG. **2** with the specific conditions and sequence indicated in Table 3.

TABLE 2

(the numbers are approximate)
Common Conditions for Process Cycle

Substrate temperature	300.° C.
Pressure	300 Pa
Carrier gas and dilution gas	Ar
Reactant gas	H_2
Flow rate of carrier/dilution gas (continuous)	2000 sccm/1000 sccm (3000 sccm total)
Purge after precursor feed pulse	1 sec
Purge after RF power pulse	1 sec
RF power	100 W
Target Thickness (nm)	10.

TABLE 3

(the numbers are approximate)

	Sequence	Feed (seconds)	Feed amount (g/cycle)	RF pulse (seconds)	Precursor	H_2 flow (sccm)
*1	FIG. 2	1	0.04	1	DVDMS	0
*2	FIG. 2	0.1	0.004	1	DVDMS	800
*3	FIG. 2	1.0	0.002	1	HMDS	0
4	FIG. 2	1	0.002	1	HMDS	50
5	FIG. 2	0.8	0.0016	1	HMDS	50
6	FIG. 2	0.6	0.0012	1	HMDS	50
7	FIG. 2	0.5	0.001	1	HMDS	50
8	FIG. 2	0.1	0.0002	1	HMDS	50
9	FIG. 2	0.5	0.001	0.5	HMDS	50
10	FIG. 2	0.1	0.0002	0.5 each	HMDS	50
11	FIG. 2	0.1	0.004	0.5 each	DVDMS	50
12	FIG. 2	0.1	0.004	1	DVDMS	50
13	FIG. 2	0.1	0.004	1	DVDMS	300

In Table 3, the Example numbers with "*" indicate comparative examples. Each obtained film was evaluated. Table 4 shows the results of evaluation. DVDMS is divinyldimethylsilane, and HMDS is hexamethyldisilane.

TABLE 4

(the numbers are approximate)

	GPC (nm/cycle)	Sidewall Coverage @AR3 (%)	Remarks
*1	0.03	35%	No damage
*2	—	—	Great damage
*3	0.12	40%	No damage
4	0.07	80%	No damage
5	0.05	85%	No damage
6	0.02	94%	No damage
7	0.009	125%	No damage
8	0.006	130%	Slight damage
9	0.007	130%	No damage
10	0.004	150%	No damage
11	0.06	85%	No damage
12	0.02	115%	No damage
13	0.01	130%	No damage

In Table 4, "GPC" represents growth rate per cycle, "Sidewall Coverage@AR3" represents a percentage of thickness of film deposited on a sidewall relative to thickness of film deposited on a blanket surface at a trench having an aspect ratio of 3, and "Remarks" describes damage observed on a surface of an underlying layer after deposition.

In the above examples, when no hydrogen gas was used as a reactant in Example 1, the sidewall coverage was significantly low, since no hydrogen gas was used, and sufficient argon plasma did not reach the sidewall of the trench, whereby sufficient active sites on the silicon-containing hydrocarbon precursor were not formed at the sidewall, i.e., the sidewall coverage was poor (35%). On the

other hand, when excessive hydrogen gas (800 sccm) was used in Example 2, etching took place particularly on the top surface, and no film was deposited. However, when an appropriate quantity of hydrogen gas was used in Examples 12 (50 sccm) and 13 (300 sccm), etching desirably took place on the top surface, thereby interfering with deposition of film on the top surface and significantly increasing the sidewall coverage (115% in Example 12; 130% in Example 13). Further, when RF power was applied in two sessions in Example 11, the etching effect by hydrogen gas became weaker, and deposition by hydrogen gas was promoted. As a result, the GPC was increased, especially at the sidewall, thereby increasing the sidewall coverage (85%) as well as the GPC (0.06 nm/cycle), as compared with Example 12 (the sidewall coverage was 115%, and the GPC was 0.02 nm/cycle) and Example 1 (the sidewall coverage was 35%, and the GPC was 0.03 nm/cycle). The above differences between Examples 11 and 12 are opposite to those between Examples 8 and 10 discussed below. This may be because in Examples 11 and 12, the precursor possessed a carbon double bond (vinyl), and when the double bond was opened by a hydrogen plasma, chemisorption and formation of dangling bonds could have been promoted, more than etching.

When the duration of feed pulse was increased from 0.1 second (Example 8) to 0.5 seconds (Example 7), 0.6 seconds (Example 6), 0.8 seconds (Example 5), and 1.0 seconds (Example 4), the GPC was increased accordingly from 0.006 nm/cycle (Example 8) to 0.009 nm/cycle (Example 7), 0.02 nm/cycle (Example 6), 0.05 nm/cycle (Example 5), and 0.07 nm/cycle (Example 4), whereas the sidewall coverage was decreased accordingly from 130% (Example 8) to 125% (Example 7), 94% (Example 6), 85% (Example 5), and 80% (Example 4). When comparing Example 4 (with 50 sccm of hydrogen gas) and Example 3 (with 0 sccm of hydrogen gas), the GPC was lower in Example 4 (0.07 nm/cycle) than that in Example 3 (0.12 nm/cycle), the sidewall coverage was significantly higher in Example 4 (80%) than that in Example 3 (40%) due to the etching effect of a hydrogen plasma which was more prominent on the blanket surface than the sidewall. When the duration of feed pulse was as short as 0.1 second in Example 8, fine damage on the surface of the substrate was observed. Further, when the duration of RF power pulse was shorter in Example 9 (0.5 seconds) than in Example 8 (1.0 second), the GPC was slightly increased whereas the sidewall coverage was substantially unchanged. Further, when RF power was applied in two sessions in Example 10 as compared with Example 8 (one session), the etching effect by hydrogen gas became stronger, and deposition by hydrogen gas was least promoted. As a result, the GPC was low (0.004 nm/cycle), as compared with Example 8 (0.006 nm/cycle). The above differences between Examples 8 and 10 are opposite to those between Examples 11 and 12 discussed above. This may be because in Examples 8 and 10, the precursor did not possess a carbon double bond, and the etching effect of a hydrogen plasma became more prominent by two-session application, resulting in lower GPC in Example 10 (0.004 nm/cycle) than that in Example 8 (0.006 nm/cycle), and higher sidewall coverage in Example 10 (150%) than that in Example 8 (130%).

Accordingly, it was confirmed that by adjusting the duration of feed pulse, the duration of RF power pulse, and/or the flow rate of hydrogen gas, the sidewall coverage and the GPC can be desirably adjusted.

It will be understood by those of skill in the art that numerous and various modifications can be made without departing from the spirit of the present invention. Therefore, it should be clearly understood that the forms of the present invention are illustrative only and are not intended to limit the scope of the present invention.

We claim:

1. A method for forming a dielectric film in a trench on a substrate by plasma-enhanced atomic layer deposition (PEALD) performing one or more process cycles, each process cycle comprising:

(i) feeding a silicon-containing precursor in a pulse to a reaction space where the substrate is placed, said silicon-containing precursor being constituted by one or more hydrocarbon-containing compounds selected from the group consisting of: SiH_2R_2, $Si_2H_2R_4$, SiR_2X_2, Si_2R_6, SiH_3R, $Si_2H_4R_2$, SiH_2RX, $C_3H_6SiH_2$, $C_2H_4SiH_2$, $C_2H_4Si_2H_2$, $SiNHSiR_4H_2$, $SiNHSiR_6$, and $SiHX_2R$, wherein each X is independently chain or cyclic CxHy, and each R is independently chain or cyclic C_xH_y, cyclic $N_xC_yH_z$, $N(C_xH_y)_2$, $N(C_xH_y)H$, $O(C_xH_y)$, or OH, wherein x, y, and z are integers;

(ii) supplying a hydrogen-containing reactant gas to the reaction space at a flow rate of more than about 30 sccm but less than about 800 sccm in the absence of nitrogen-containing gas;

(iii) supplying a noble gas to the reaction space; and

(iv) applying RF power to the reaction space in the presence of the hydrogen-containing reactant gas and the noble gas and in the absence of any precursor in the reaction space, to form a monolayer constituting a dielectric film on a substrate at a growth rate of less than one atomic layer thickness per cycle.

2. The method according to claim **1**, wherein the growth rate of the monolayer is less than 0.1 nm/cycle.

3. The method according to claim **1**, wherein the precursor has a chemical formula where at least one of X or R is an unsaturated hydrocarbon.

4. The method according to claim **1**, wherein the precursor has a cyclic structure.

5. The method according to claim **1**, wherein the silicon-containing precursor is one or more compounds selected from the group consisting of: dimethylsilane, divinylsilane, dipyridylsilane, tertamethyldisilane, divinyldimethylsilane, dimethyldipyridylsilane, hexamethydisilane, silylacetylene, allylsilane, divinyldisilane, dimethyldisilane, viylmethylsilane, silacyclobutane, silacycloethane, di silacycloethane, tetramethyldisilazane, hexamethyldisilazane, and dimethylpridyldisilane.

6. The method according to claim **1**, wherein the reactant gas is hydrogen gas.

7. The method according to claim **1**, wherein the noble gas is argon.

8. The method according to claim **1**, wherein the reactant gas is supplied continuously to the reaction space throughout each process cycle.

9. The method according to claim **1**, wherein the noble gas is continuously supplied to the reaction space throughout the process cycle.

10. The method according to claim **1**, wherein a ratio of flow rate of the noble gas to flow rate of the reactant is about 10:1 to about 60:1.

11. The method according to claim **1**, wherein in step (iii), the noble gas is supplied to the reaction space at a flow rate of about 1,000 sccm to about 5,000 sccm.

12. The method according to claim **1**, wherein in step (iv), no gas other than the reactant gas and the noble gas is supplied to the reaction space.

13. The method according to claim **1**, wherein in step (i), the silicon-containing precursor is fed in an amount of about

0.00002 g/cycle to about 0.01 g/cycle and in a pulse having a duration of about 0.1 seconds to about 1.0 second.

14. The method according to claim **1**, wherein each process cycle further comprises a purging step between steps (i) and (iv), and between steps (iv) and (i) when the process cycle is repeated.

15. The method according to claim **1**, wherein in step (iv), RF power is applied to the reaction space in two occurrences between which a purging step is conducted.

16. The method according to claim **1**, wherein in step (iv), RF power applied to the reaction space is about 0.028 W/cm^2 to about 0.28 W/cm^2.

17. The method according to claim **1**, wherein the temperature during the process cycle is about 50° C. to about 500° C.

18. The method according to claim **1**, wherein the dielectric film is a film of SiC, SiCN, SiN, SiOCN, or SiO.

19. The method according to claim **1**, wherein a sidewall coverage of the deposited dielectric film is about 80% or higher, wherein the sidewall coverage is defined as a ratio of thickness of film on a sidewall of the trench to thickness of film on a blanket surface of the trench.

20. A method for increasing a sidewall coverage of a dielectric film deposited according to claim **1** wherein in step (i), the precursor is fed in a pulse having a first duration, in step (ii), the reactant gas is supplied at a first flow rate, and in step (iv), RF power is applied in a pulse having a first duration, and the dielectric film has a first sidewall coverage, said sidewall coverage being defined as a ratio of thickness of film on a sidewall of the trench to thickness of film on a blanket surface of the trench, said method comprising:

(a) setting a second duration of the pulse of the precursor in step (i), a second flow rate of the reactant gas in step (ii), and a second duration of the pulse of RF power in step (iv), wherein at least one of the second flow rate of the reactant gas and the second duration of the pulse of RF power is higher than the first flow rate of the reactant gas and the first duration of the pulse of RF power, respectively, and/or the second duration of the pulse of the precursor is shorter than the first duration of the pulse of the precursor; and

(b) repeating steps (i) to (iv) using the second flow rate of the reactant gas and the second duration of the pulse of RF power, thereby depositing a dielectric film having a second sidewall coverage which is higher than the first sidewall coverage.

* * * * *